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JAN 79 R H MITCHELL, J W ASCHENBACH

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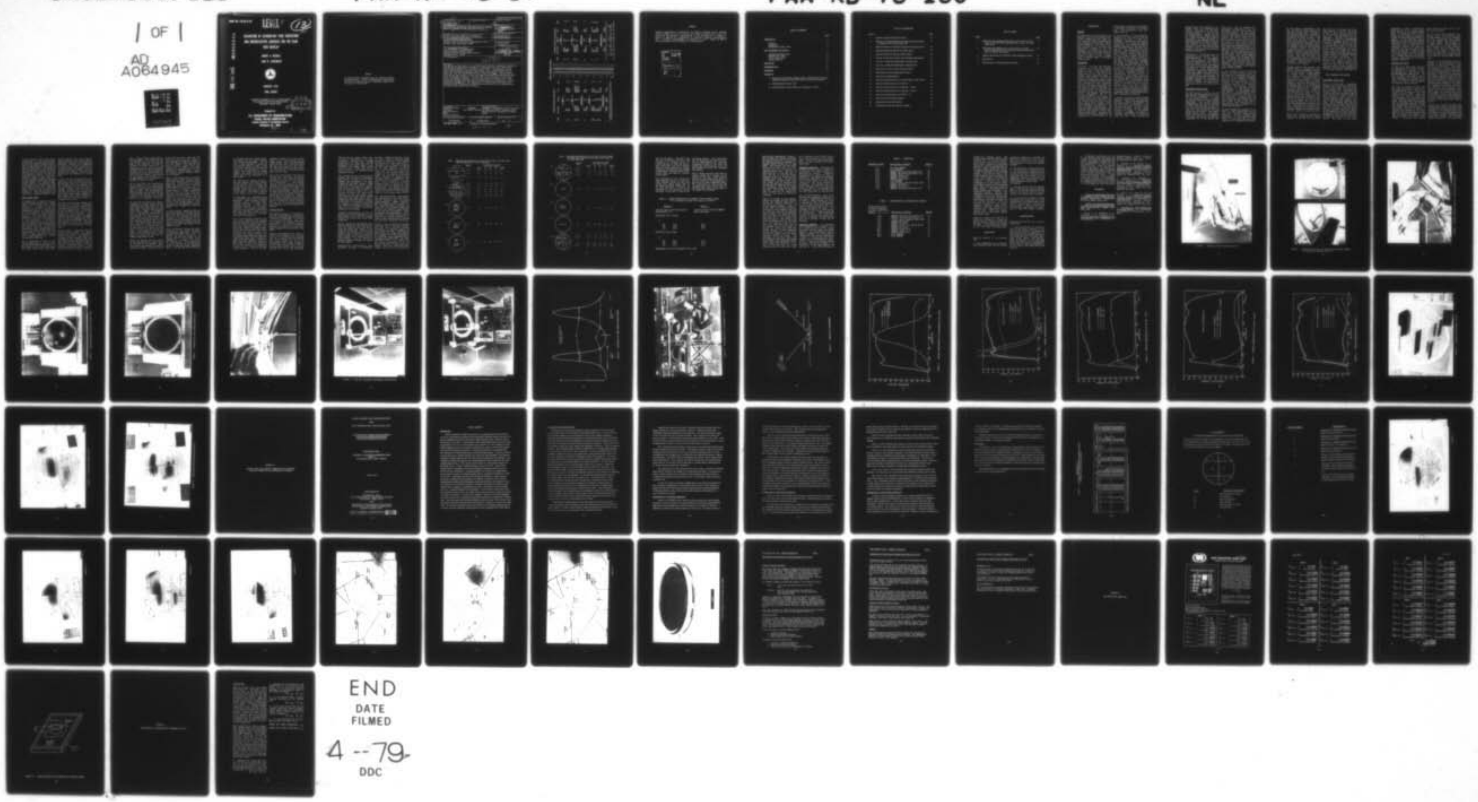

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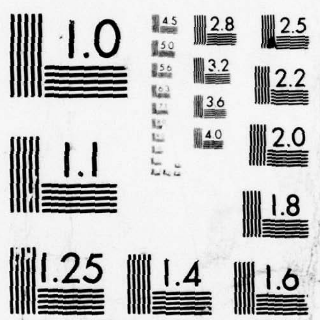

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EVALUATION OF CATHODE-RAY TUBE PROTECTION AND ANTIREFLECTIVE SURFACES FOR THE PLAN VIEW DISPLAY

ROBERT H. MITCHELL

JOHN W. ASCHENBACH

JANUARY 1979

FINAL REPORT

Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
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16. Abstract

The purpose of this report is to describe the evaluation of implosion protection systems and antireflective surfaces for cathode-ray tube (CRT) used in plan view displays (PVD's) for air traffic control (ATC). An implosion forcing device was fabricated utilizing coolant spray and a carbide-tipped punch to impact the critical CRT shoulder area to induce implosions. Results showed that none of the six CRT's tested utilizing the Kimcode®-type implosion system could be imploded violently. Ten other CRT's were evaluated for antireflectivity and optimum resolution. Various antireflective surfaces were tried. Subjective analysis indicated that an etched surface was sufficient to reduce reflections for ATC use. The combination of etch and High Efficiency Antireflective (HEA)® coating was judged most antireflective, but fingerprints on the HEA-coated surface could be seen.

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METRIC CONVERSION FACTORS

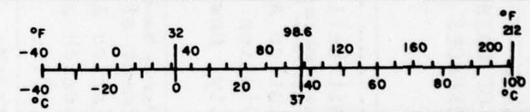
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



PREFACE

Grateful appreciation is conveyed to Mr. Elmer M. Haynack and Mr. Salvador Roditi of ANA-170 for their timely and extensive assistance in the data collection and analysis. Appreciation is also conveyed to Dr. Richard L. Sulzer of ANA-230 for formulating the subjective analysis questionnaire. Also, a special acknowledgement is expressed to Alan J. Kopala of ARD-113 for his assistance in the completion of this project.

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INTRODUCTION

PURPOSE.

The objective of this project is to develop a safe and antireflective 23-inch cathode-ray tube (CRT) for use in Federal Aviation Administration (FAA) air route traffic control centers (ARTCC's). The intent of the CRT redesign is to increase the mechanical strength of the CRT envelope, to reduce the risk of implosion, and to attenuate the glare and reflections on the viewing surface in order to allow a higher level of ambient light in the ARTCC control room.

BACKGROUND.

In 1973, a 23-inch CRT imploded violently in a plan view display (PVD) at the Cleveland ARTCC (Oberlin, Ohio). The display was being used at the time by an air traffic control specialist (ATCS) to control air traffic. He was not injured, although small glass fragments were scattered around the PVD for a distance of 6 feet. Representatives of Corning Glass Works, who made the CRT bottle; Raytheon Co., who made the CRT and the PVD; and representatives of FAA/National Aviation Facilities Experimental Center (FAA/NAFEC) met at the Cleveland ARTCC to inspect the display, which had been removed to the maintenance area. Both the inner and outer glass surfaces of the safety glass outer viewing surface were fragmented, but adhered to the layer of plastic between them. The scattered small glass fragments came from the outer surface of the safety glass writing panel. Engineers from Corning Glass Works transported the remains of the CRT back to the Corning Glass Laboratory for analysis to determine the cause of the implosion. Upon examination, they were unable to do so.

An investigation of the mechanical integrity of the 23-inch CRT was carried out in 1973, '74, and '75 by FAA/NAFEC, Underwriters Laboratories (reference 1), Raytheon Company (appendix A), and Corning Glass Works. Various theories as to why the CRT at the Cleveland ARTCC imploded were explored. The consensus of opinion from the glass and CRT industries was that a scratch, no matter how minute, on the critical shoulder area of the CRT could be the source of failure at any time from the instant the scratch was made. Following this, FAA/NAFEC was tasked to investigate the cause of the CRT implosion and how the CRT or the PVD could be modified to retain any flying glass fragments in the case of a violent implosion. In conclusion, FAA/NAFEC decided to investigate the feasibility of employing a Kimcode-type implosion protection system (reference 2) on the 23-inch CRT. The Kimcode system consists of a four-piece steel shell which is fastened to the critical shoulder area of the CRT to counteract the forces that cause an implosion. The Kimcode system is a product of Owens-Illinois, Incorporated, and is registered under United States Patent Nos. 3,220,592 and 3,220,593.

A second, unrelated problem became apparent shortly after the implosion occurred. Digital narrow-band radar was introduced to the ARTCC's, and the PVD's were reconfigured to the near-vertical mode. In this configuration, specular (mirror image) reflections became a significant problem. FAA/NAFEC was asked to reexamine the problem of reflections from the CRT. The problem had

existed since the inception of air traffic radar, and although prior efforts (reference 3) had been directed towards it, it had not been a pressing problem. However, the use of a near-vertical primary display for control increased the amount of reflections, and a maximum effort was undertaken toward solving the reflection problem, since the specular reflections from opposing display surfaces, walls, and ceiling were visible on the faces of the vertical displays (reference 4).

Preliminary investigations as requested by Air Traffic Service (9550-AAT-100-34), of the problem, were undertaken at FAA/NAFEC. Potential improvements were identified (reference 5 and 6), and an evaluation of potential improvements was conducted at the Boston ARTCC (reference 4). These investigations reduced the number and intensity of light source images that were visible on the PVD face. To solve both the reflection and implosion problems, an FAA/NAFEC project was initiated by Systems Research and Development Service (SRDS) to develop an implosion-proof, antireflective CRT.

PRELIMINARY PROJECT WORK.

The PVD console in which the CRT imploded was shipped from the Cleveland ARTCC to FAA/NAFEC to be used for the implosion tests. A system was devised that would create violent implosions. For a safer PVD/CRT configuration, the PVD was modified to allow sufficient air to rush into the tube area through openings so that the "safety glass" writing surface on the front of the display would remain intact. Drilling a series of holes in the antimagnetic cone that surrounds the CRT was considered, but it was decided that there was a risk of damaging the antimagnetic properties of the cone and there would be difficulties in field modification. The next attempt involved separating the bezel containing the safety glass writing surface away from the front of the PVD so that air could rush in around the edge of the bezel without breaking the safety glass shield. This design was abandoned when it was found that the bezel would have to be separated so far from the face of the CRT that it would seriously reduce the angle that an ATCS would view the entire screen. Also, glass fragments could be thrown out upon implosion of the CRT through the resultant opening. These two modifications were implosion tested before they were abandoned, and violent implosions still caused breakage of the "safety glass" writing surface.

It was decided that the "safety glass" writing surface must be replaced with something that would not break if an implosion occurred. Discs of all the readily available plastics were surveyed. These included all types of acrylics and variants thereof, with special toughening procedures, surface hardening, etc., applied by their manufacturer. It was finally found that Lexan®, a polycarbonate manufactured by General Electric Co., would not break under the force of the implosion. A Lexan panel, 3/8 inch thick, was substituted for the safety glass writing surface held by the bezel and successfully withstood the force generated by an induced CRT implosion.

The FAA subsequently equipped all the PVD's in their operational facilities with 1/4-inch Lexan writing surfaces. The only problem with these panels is that they are susceptible to scratches and for that reason must be replaced periodically.

At this stage in development of the CRT, the PVD was being converted to the near-vertical mode of operation. Reflections became such a problem in the operating facilities that it was decided to attempt to make a CRT which would not only be safer, but would, at the same time, reduce glare and reflections to a minimum. One of the original trials was with Raytheon Co. bonding a sheet of 1/4-inch Lexan to the face of a CRT. The Lexan was sagged to conform to the curvature of the CRT. Only one sample was tested, and an induced CRT implosion was violent. The Lexan was drawn into the antimagnetic shield, and although the shield bulged inward due to air pressure, nothing came out of the front of the display.

Another product was tested, also manufactured by General Electric. This is called Lexguard® and consists of two thin pieces of glass bonded to a Lexan center. Unfortunately, this product was only produced in flat sheets. Although several implosions proved that it allowed nothing to come through the front opening of the PVD, the thickness of the bonding agent at the curved edges of the CRT made the use of Lexguard optically impractical. Problems developed when the outer surface of the Lexguard was etched to reduce glare. Although there was some deterioration of the sharpness of the observed characters or lines on the PVD in the center area of the CRT, the deterioration of lines at the edge was unacceptable for operational use. Resolution deteriorates in a direct proportion to the optical distance between the phosphor layer and the etched writing surface.

While prior implosion testing has shown that a Lexan shield bonded directly to the CRT will not allow any glass to be thrown out of the front opening of the PVD, the Lexan surface is not as hard as glass and can be scratched, becoming hazy after long use. Corning Glass Co. had developed a chemically strengthened, semiflexible glass called Chemcor®. Therefore, FAA/NAFEC decided to bond a 1/8-inch sheet of Lexan to the face of the CRT, and a piece of 0.050 inch (50 mil) thick Chemcor on top of the Lexan. Both were sagged to conform to the shape of the tube face. This allowed a shorter distance between the etched surface and phosphor surface which increased resolution. This modified CRT also utilized the Kimcode-type implosion protection system. This safety system reinforces the rim area of the tube and does not permit stress changes and subsequent cracking during devacuation of the tube envelope (reference 2).

TEST PROCEDURES AND RESULTS

PRELIMINARY SAFETY TEST.

Early in the project, FAA/NAFEC designed and fabricated an implosion-forcing device that utilized a heat gun, a coolant spray, and a push-type solenoid (figure 1). It was felt that if stress could be induced by heating and/or cooling one area of the CRT and then striking it with a punch, a violent implosion might result. Only one CRT implosion was attempted with heat. The cellophane tape that was wrapped around the edge of the CRT and the epoxy that held the glass safety panel to the face of the CRT melted and quite probably could have ignited had the application of heat continued. An application of cold spray was next attempted to create an area of stress. The CRT was struck by a tool steel punch. The point of the punch

mushroomed on impact, necessitating substitution of a carbide-tipped punch. The use of this carbide-tipped punch, in conjunction with a can of coolant spray, produced a successful system for generating implosions on command. As the implosion testing began, about every other CRT imploded violently. Of the 43 original unmodified CRT's used in these tests, 21 imploded violently. In every case utilizing the chill and punch technique, the CRT was at least cracked across the faceplate, which resulted in it devacuating. With the eleventh CRT, a violent implosion ocurred that closely duplicated the Cleveland implosion (figure 2).

MODIFIED TEST CRT'S.

A total of 21 CRT's were delivered for evaluation with either an etch, an antireflective coating, or both, by Raytheon Co., FAA contract No. DOT-FAA-76NA-3029 (appendix A). The first 10 CRT's (see tables 1 and 2) were designated for electro-optical tests and subjective analyses in the PVD's; the last 11 were designated for implosion safety testing.

The first two tubes were built with the same protective features as the present-type CRT's. They incorporated the fiberglass boot and safety implosion panel. They were modified to have an additional 1/4-inch panel of Lexan between the glass implosion panel and the faceplate. All other tubes were equipped with the fiberglass boot and utilized the Kimcode-type implosion system. This safety system consists of a four-piece steel shell formed to surround the shoulder of the tube, which is the critical implosion area. This is bonded to the glass of the CRT and, before the bonding agent cures, is tensioned with a metal strap around the widest part of the bell over the shell.

The first five CRT's employed, for optical tests, 1/4-inch thick panel of Lexan bonded to the CRT faceplate with the original-type glass implosion panel bonded atop the Lexan for an outer surface. The remainder of the CRT's had a 1/8-inch layer of Lexan bonded to the CRT faceplate with a 50-mil layer of Chemcor glass bonded to the outside of the Lexan. This was necessary to reduce the total thickness of the bonded package to achieve the desired image resolution.

Nineteen of the outer panels, prior to bonding to the CRT faceplate, were shipped to Eagle Convex Co., where they were acid etched. The degree of coarseness of the etch was carefully controlled and was determined by placing the etched panel 1 1/2 inches away from a 1951 Air Force Resolution test target (appendix B) and resolving the smallest possible element of line pairs (appendix B). There are six elements in each group on the target, and resolution improves as the group and element-type numbers increase. For example, the reading "3:1" indicates, for that particular etched panel, that the line pairs in the first element of the third group could be resolved. The 3:1 etch turned out to be the finest resolution attainable in order to maintain a uniform distribution of etch over the viewing surface.

Seven of the optical test CRT's also incorporated a special antireflective coating on their outer surfaces. This coating is a multilayer dielectric film which is a precisely phased array of suitable optical interfaces that effectively decreases the air-glass index discontinuity. The wave nature

of the incident light rays causes reflections at this discontinuity. By effectively decreasing the difference in the index of reflectivity at this air-glass boundary, this coating reduces reflections. Two brands of this coating were used by the manufacturer of the test CRT's, but both were supposed to meet the same reflectance specification. This specification allows no more than 0.4-percent average reflectance between the wavelengths of 425 and 700 nanometers, which is the response range of the human eye to light. Also, the specification called for an absolute peak reflection of less than 0.6 percent for the range of 450 to 650 nanometers. These measurements are done at an incident angle of 60°.

FINAL SAFETY TESTS.

The method used to implode the original CRT design consisted of a single spray can of coolant and a punch (figure 3). In order to test the modified test CRT's having the Kimcode-type system, a new mechanism was built (figure 4) that could spray up to five cans of coolant simultaneously. The extra cans would be available in case the "heat sinking" of the metal made it difficult for the temperature of the impact point to decline to the same point as the original-type tube. It was found that four cans were sufficient. Measurements with thermocouples and chart recorders showed that the temperature of the glass on both types of tubes lowered 30° Celsius (C) to approximately -8° C in 30 seconds and leveled off.

All 11 implosion-test CRT's of the final design had a 1/2-inch hole drilled in the Kimcode-type shell for the carbide point to hit the glass. The first two of these CRT's were tested using the four cans of coolant and the carbide point. There were no implosions, and the CRT's maintained structural integrity. On examination of each CRT, a "pock" was found in the glass where the carbide tip had chipped the glass surface, but this was the only damage. Each CRT was devacuated by breaking the glass neck.

A steel rod was sharpened and centered over the 1/2-inch hole in the Kimcode-type shell of the third tube. The coolant spray was repeated, and the rod driven into the tube with a 4-pound hammer. The tube did not implode. Evidence that the bulb of the CRT had cracked was found only after many small cracks appeared in the Chemcor front panel (figure 4). This CRT was also devacuated by breaking off the neck.

The steel rod had been blunted after testing the third CRT. Therefore, one end of the rod was drilled and a centerpunch inserted. The centerpunch was hammered into a fourth CRT at the 1/2-inch hole until a crack appeared on the faceplate. After several more blows with the hammer, the tube did not implode, but devacuated as the centerpunch fell into the interior of the CRT. The tube had several cracks on the faceplate, but was still basically in one piece.

At this point, it was felt that the spray coolant might not induce sufficient stress for a successful forced implosion. Therefore, a 15-pound carbon dioxide (CO_2) fire extinguisher was discharged onto the area near the hole in the rim band on the fifth tube tested. After a 2-minute discharge showed a frost buildup around the hole, a centerpunch was again driven into the

CRT. After several blows with a 4-pound hammer, this fifth CRT did not implode, but cracked near the edge of the faceplate. The CRT was allowed to remain quiescent for several hours to return to room temperature, and the crack progressed to the center of the faceplate. Breaking the neck showed that the tube still held vacuum. Observation of the impact hole showed it to be approximately 1/2-inch deep with a diameter of about 1/4 inch.

On the sixth CRT, the tension band was purposely cut to determine whether or not the tube would implode when no tension was on the Kimcode-type rim band. The centerpunch was driven through the rim band, and the tube did not implode, but instead cracked on the faceplate and slowly went to air (figures 5 and 6).

It was then decided that before applying the coolant spray, possibly scratching the glass surface at the point where the punch hits the tube would cause a violent implosion when struck with a hammer. To accomplish this, a seventh tube was mounted in the display with the hole in the Kimcode-type rim band toward the right. The tube was rotated 90° from the original position used in the test. The coolant spray outlet tubes were relocated to cool the area to be struck. A 1/2-inch hole was drilled through the console to allow entry of the rod that holds the punch. The mounting of the seventh tube in this position made it possible to strike the rod with the hammer using greater force.

Before the seventh tube was cooled, it was scratched with a glass cutter at the hole in the Kimcode. Next, the coolant was sprayed for about 45 seconds, as before. Then the rod was driven into the tube. After the tube had been struck several times, a crack appeared through the middle of the tube faceplate starting from the point of impact. After several more blows with the hammer, the glass envelope was punctured and the tube devacuated in approximately 1 second. The outside surface (Chemcor panel) was not damaged.

Next, it was thought that if the punch impacted with a much stronger force, this could possibly induce a violent implosion. Therefore, the 4-pound hammer was replaced with a 10-pound sledge hammer in the next test. In the first trial using the 10-pound sledge hammer, a normal, unmodified CRT was set up in the implosion display in the same manner as the last implosion test. As before, the CRT glass was cooled in the area of impact, and then struck with the punch driven by the sledge hammer. After one blow, the CRT imploded violently, throwing glass fragments out onto the floor.

A second normal, unmodified CRT was set up and tested in the same manner. When this tube was hit once with the punch, it also imploded violently, throwing a large section of the implosion panel and faceplate onto the floor, and smaller pieces of glass against the walls and windows of the implosion room.

After successfully proving the effectiveness of the latest technique for imploding normal CRT's, one of the modified test CRT's was set up. As before, the tube was mounted in the display with a 1/2-inch hole in the Kimcode-type rim band to the right, 90° from the top. The procedures to test this tube were in the same manner as the two previous normal, unmodified CRT's. The tube was first cooled for

45 seconds with the coolant spray, then struck with the punch driven by the 10-pound sledge hammer. In this test, it was necessary to strike the tube several times to cause a crack to proceed horizontally through the center of the faceplate. After several more blows with the sledge hammer, the punch punctured the glass, and the tube devacuated in a few seconds.

The tube did not implode violently. The only damage to the tube, besides the horizontal crack already mentioned, was an area of cracked and chipped glass about 3 inches in diameter around the point of impact of the punch. The Chemcor and the Lexan panels were not damaged.

At this point, all reasonable means of imploding these CRT's appeared exhausted. Under extremely violent testing, none of the eight CRT's imploded violently. In fact, they remained basically in one piece. Therefore, all further implosion testing of the implosion test article CRT's was canceled in order to save the remaining tubes for possible field use and evaluation.

Two of the unbroken Chemcor/Lexan front panel sandwiches were removed from the implosion test-article CRT's after they were implosion tested and were sent to Thomas Electronics, Inc. Along with these, two normal, unmodified, used 23-inch CRT's with poor emission (no longer useful in a display) were also shipped, and the normal glass implosion panel was replaced by Thomas with the Chemcor/Lexan combination panels. These two CRT's were then implosion tested at NAFEC under the same test conditions as the last trial of an implosion test article CRT (using the 10-pound sledge hammer). The first CRT imploded violently after the initial impact of the punch driven by the sledge hammer, but the Chemcor/Lexan panel did not crack. When the second CRT was first hit with the punch, the faceplate cracked and went to air in a few seconds. The Chemcor/Lexan panel did not crack.

All 19 test article CRT's that had the Kimcode-type implosion protection system were air pressure tested according to method 1141 of MIL-STD-1311 (reference 7). This method requires that the pressure be slowly increased to 30 pounds per square inch (psi) above normal at the rate of 1 psi per second inside a pressure tank in which the CRT rests. The pressure is then held for 60 seconds at 45 psi. After this, the pressure is released. All 19 CRT's sustained this pressure for 60 seconds except one which failed after 37 seconds of 45-psi pressure. This was one of the implosion sample test articles. The front surface held together.

OPTICAL QUALITY.

The optical quality of 10 antireflective CRT's was measured utilizing the Display Performance Test Set (figures 7 and 8) at FAA/NAFEC. This test set consisted of various power supplies, meters, oscilloscopes, function generators, and other equipment necessary to properly bias and thoroughly evaluate the total array of FAA CRT's.

Linewidth measurements were taken of single lines displayed at a writing rate of 0.3 inches per microsecond (μs) and a refresh rate of 60 hertz (Hz). Light output was set at 50 footlamberts (fL), average brightness for the single lines of data. This is conservatively higher than the normal setting of 15 fL or less presently

used by the air route traffic controllers in the ARTCC's. The line brightness, measured with a GAMMA Scientific Inc. Model No. 700-10A photometric microscope (figure 7) was calibrated for single lines between 10 mils (1 mil = 0.001 inch) and 20 mils of width at the 50-percent peak brightness points.

The linewidth was then measured between the 50-percent peak-brightness points of the line at 50-fL average line brightness. The measurement was performed using a GAMMA Scientific Model No. 700-10-1 microscope with a scanning-slit aperture with an effective size of roughly 1 mil by 40 mils (figure 8). The longer dimension was positioned parallel to the line under test. This aperture was then slowly scanned across the line under test to give a brightness-versus-position presentation such as illustrated in figure 9. However, the data in figure 10 were taken at an average line brightness of 30 fL in order to show the comparison on one graph.

Linewidth measurements at the 10-percent points were performed in the same manner, now using the distance between the points with this lower brightness.

Angular resolution measurements were also performed in the same manner, with the exception that the microscope was angled with respect to the faceplate of the CRT. This was done because light dispersion on etched panels causes a loss in resolution when viewing data through them at sharp angles. The "D" controller position requires viewing the display at these angles.

Reflectivity measurements were performed utilizing a reflectometer assembly. (GAMMA Scientific Model No. 191A), which is depicted being operated in figure 10. This assembly incorporates a light source with a relatively flat frequency response over the light spectrum. It can be set at equal angles of incidence (θ_1) and reflection (θ_2) with respect to the surface under test (figure 11). The amount of reflected light entering the receptor from the test surface is compared to that reflected from a standard flat surface. This standard is a smooth polished piece of glass, the back surface of which is coated with a flat black paint. The amount of light reflected off this standard surface is roughly 28 percent of the incident light at an incident angle of 60°.

The spectroreflectivity measurements were performed with this same reflectometer assembly and a scanning spectroradiometer (GAMMA Scientific Model No. 3000) pictured in figure 10. The spectroradiometer separates the light into its component frequencies and plots the amount of light present at the various wavelengths. These measurements were performed to see if the etches or coatings varied in their response to various frequencies of light, because antireflective coatings are generally frequency selective.

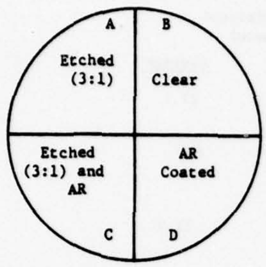
Tables 1 and 2 show the average resolution (at the 50-percent points) near the center and the average reflectivity at different angles for the optical-test CRT's. Referring to these tables, and using the criterion of a maximum of 12-mil linewidth at the 50-percent peak brightness points (specification FAA-E-2573), the first four CRT's (Nos. 1, 2, 3, and 4) had the widest linewidth of all 10 optical-test CRT's in areas that were etched. These four tubes also had a coarser etch (1:5 to 2:5) than the

TABLE 1. RESOLUTION AND REFLECTIVITY OF FIVE CRT'S UTILIZING A 0.19-INCH GLASS IMPLOSION PANEL ATOP A 1/4-INCH LEXAN PANEL

	Region	Resolution (mils)	Average Reflectivity in Percent (θ is angle of incidence) θ = 80°	60°	45°	37°	Average
No. 1	A Etched (1:6)	A 14.4	19.8	23.6	30.1	35.0	27.1
	B Clear	B 11.5	100	100	100	100	100
	C Etched (2:5)	C 14.3	26.5	29.3	35.8	40	32.9
No. 2	A HEA and Etch (2:6)	A 14.9	2.0	3.6	8.8	16.0	7.6
	B Etched (2:6)	B 14.8	30.5	34.5	40.5	45.5	37.7
	C HEA Coated	C 10.0	8.8	14.4	27.5	39.0	22.4
	D Clear	D 10.4	100	100	100	100	100
	E HEA & Etch (2:2)	E 15.1	1.4	2.1	5.5	10.0	4.7
	F Etched (2:2)	F 15.1	19.0	22.0	26.5	31.5	24.7
No. 3	Etched (2:6) and HEA Coated; Kimcode - Type Shell	13.8	2.1	4.4	11.6	19.7	9.4
No. 4	Etched (2:6); Kimcode - Type Shell	13.2	42.8	45.0	50.8	57.8	49.0
No. 5	HEA Coated; Kimcode - Type Shell	11.7	4.4	5.3	13.5	21.6	11.2

TABLE 2. RESOLUTION AND REFLECTIVITY OF FIVE CRT'S UTILIZING KIMCODE-TYPE SHELLS AND A 0.050-INCH-THICK CHEMCOR GLASS PANEL ATOP A 1/8-INCH LEXAN PANEL

No. 6



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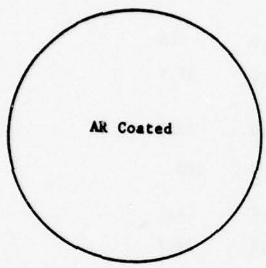

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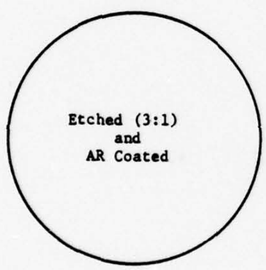
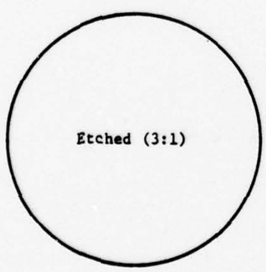
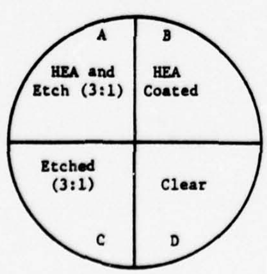


No. 9



No. 10



		Resolution (mils)	Average Reflections in Percent (θ is angle of incidence)				
			θ = 80°	60°	45°	37°	Average
No. 6	A	11.9	70	73	77	79	74.75
	B	11.6	97	94	95	95	95.3
	C	11.2	7.8	8.1	10.0	10.7	9.2
	D	11.8	6.6	7.5	14.7	25.0	13.4
No. 7		11.1	3.9	4.8	14.4	25.4	12.1
No. 8		12.4	6.9	7.1	15.4	19.7	12.3
No. 9		11.4	52.4	55.0	60.8	66.6	58.7
No. 10	A	11.3	6.1	3.2	7.5	17.4	8.5
	B	11.4	8.8	4.4	9.4	22.5	11.3
	C	11.2	64.9	66.6	70.6	76.8	69.7
	D	11.3	100	100	99.0	99.0	99.5

rest of the CRT's. The CRT's with the best resolution were No.7 (AR coated) No. 9 (etched) and No. 10 (combinations of HEA and etch). These three CRT's all had a 1/8-inch layer of Lexan covered with 50 mils of Chemcor, showing that the thinner etched panels provided better resolution than the earlier, thicker etched panels.

The linewidth at the 10-percent peak-brightness points on a tube in a clear (normal) section of the front surface was roughly double that at the 50-percent points (figure 9). On the first tube with a 1:6 etch, the linewidth at the 10-percent points was about triple what it was at the 50-percent points. This measurement was performed because the eye will see to approximately the 10-percent brightness points of the line even though most specifications still use the 50-percent points for linewidth meaurements.

Table 3 shows resolution data taken at various angles with respect to the surface of the CRT. These measurements were taken between the points on the line that were at approximately 10 percent of the peak brightness output. The linewidths for the etched CRT increased much more rapidly than for the AR-coated surface as the angle to the normal view increased.

TABLE 3. ANGULAR RESOLUTION AT 10-PERCENT PEAK BRIGHTNESS POINTS
(θ is viewing the angle with respect to surface)

	CRT No. 4	CRT No. 7
	1/4-inch Lexan, 0.19-inch Implosion Panel,Etched (2:6)	1/8-inch Lexan 0.050-inch CHEMCOR Panel, AR coated
Horizontal line in center		
θ		
90°	27.8	16.6
45°	37.0	16.4
30°	42.0	19.4
Horizontal line at edge		
θ		
90°	19.0	15.2
45°	34.9	16.7
30°	43.5	17.2

Measurements in mils (thousandths of an inch)

Reflectivity measurements (tables 1 and 2) showed the relative percentage of light reflected off of the various CRT viewing surfaces as compared to a standard smooth surface at the same angle. The surfaces with the lowest reflectivity were the five that employed both an antireflective coating and an etch. The best of these were No. 2, with HEA and 2:5 etch, and No. 6, with AR coating (another brand of antireflective coating) and 3:1 etch. The next best antireflective surfaces were those only coated with an antireflective coating. The AR-coated surfaces, with one exception, (CRT No. 6) showed more reflectivity than the CRT coated with HEA. The percent of reflected light increased on all sample surfaces as the angle of incidence decreased.

Figures 12 through 16 show spectro-reflectivity graphs that were plotted showing the relative amplitudes of the light reflected off of the various sample surfaces. Figure 12 is the plot of the spectral characteristics of the incident light and the reflected light off the standard smooth surface. The figure indicates that the amount of incident light reflected off of the surface was about 28 percent. Also shown is the relative response curve for the human eye. The response curve for the reflected light was then used as the standard curve for figures 13 through 16. These curves show that various degrees of etch attenuated reflected light by a relatively constant percentage over the entire frequency band for light. The coatings, on the other hand, were more frequency selective, even though in most cases they attenuated reflections better than the etches. However, in one case (No. 6), the AR coating actually allowed more light to be reflected in the "blue" area of the spectrum than a clear glass panel. This would explain why CRT's with the AR coating had bluish reflections.

TECHNICAL ANALYSIS. The data are divided into two basic catagories, resolution and effectiveness of antireflective surface. Resolution measurements of under 12.5 mils of linewidth at the 50-percent brightness points were comparable to the normal 23-inch CRT under the same test conditions and were considered acceptable. The surfaces that produced readings below 12.5 mils are listed in table 4 in increasing order of linewidth; that is, the CRT with the best resolution is listed first.

For antireflectivity, only those surfaces with comparable resolution to the normal, unmodified CRT are listed in table 5. These surfaces are listed in descending order of effectiveness. It can be seen from this table that *those surfaces with both an etch and a* coating performed the best. One exception is CRT No. 8, which had an AR coating with a higher percentage of reflectivity. The second best category of surfaces was those CRT's with just a coating. The HEA coatings were more effective than the AR coatings.

SUBJECTIVE ANALYSIS. An evaluation team composed of personnel from Air Traffic Service (ATS), Airway Facilities Service (AFS), and System Research and Development Service (SRDS) responded to a questionnaire (appendix C) that had been prepared as a guide for evaluating the effectiveness of the antireflective treatments. A tally of the various answers is shown. The CRT in "console T," as referred to in the questionnaire, was CRT No. 9. This CRT utilized an

TABLE 4. RESOLUTION

Linewidth in mils	Description of Surface	CRT No.
11.1	AR Coated CHEMCOR	7
11.2	Clear CHEMCOR	6
11.2	CHEMCOR, AR Coated and Etched (3:1)	10
11.3	CHEMCOR, HEA Coated and Etched (3:1)	10
11.3	CHEMCOR, Etched (3:1)	10
11.4	CHEMCOR, HEA Coated	10
11.4	CHEMCOR, Etched (3:1)	9
11.6	Clear CHEMCOR	6
11.7	1/4-inch Lexan, Implosion Panel, HEA	5
11.8	CHEMCOR, AR Coated	6
11.9	CHEMCOR, Etched (3:1)	6
12.4	CHEMCOR, AR Coated and Etched (3:1)	8

TABLE 5. EFFECTIVENESS OF ANTIREFLECTIVE SURFACE

Average Reflectivity (in Percent Compared to Clear, Smooth Glass Surface	Description of Surface	CRT No.
8.5	CHEMCOR, HEA Coated and Etched (3:1)	10
9.2	CHEMCOR, AR Coated and Etched (3:1)	6
11.2	1/4-inch Lexan, Implosion Panel, HEA	5
11.3	CHEMCOR, HEA Coated	10
12.1	CHEMCOR, AR Coated	7
12.3	CHEMCOR, Etched (3:1) and AR Coated	8
13.4	CHEMCOR, AR Coated	6
58.7	CHEMCOR, Etched (3:1)	9
69.7	CHEMCOR, Etched (3:1)	10
74.7	CHEMCOR, Etched (3:1)	6
95.3	Clear CHEMCOR	6
99.5	Clear CHEMCOR	10

etched (3:1) Chemcor panel. The questionnaire indicates the unanimous opinion that the etched surface sufficiently reduced reflections, while still preserving acceptable resolution, and was satisfactory for ATC use. Table 4 shows that CRT No. 9 reduced reflections to 58.7 percent of what was reflected off the normal surface. This was the best of any etched surfaces with no coating, but it was still roughly five times the light reflected from the coated surfaces. However, the light reflected off of the etched surface is diffused and much less distracting than light reflected off a smooth glass surface. The HEA-coated (no etch) surface was preferred to the etched-only surface. However, most reviewers preferred, overall, the combination of etch and HEA coating. A number of observers noted that fingerprints were more noticeable on the coated surfaces. This was because the natural oil on the fingertips tended to reduce effectiveness. What was visible to the observer were fingerprints with a blueish tint. These were easily removed with a spray glass cleaner and a paper towel.

Figure 17 shows a normal PVD as presently configured. Figure 18 shows a PVD as it would look with the new type of CRT installed and figure 19 shows a four-section CRT (number 10) in the same configuration.

CONCLUSIONS

From the results, it is concluded that:

1. The combination of the Chemcor/Lexan implosion panel and the Kimcode protective banding has increased the mechanical strength of the 23-inch CRT. The safety tests have demonstrated that it could not be forcibly imploded.

2. The combination of HEA coating and 3:1 etch on the viewing surface of the Chemcor/Lexan implosion panel provided optimal attenuation of front-surface reflections without degrading display resolution and brightness. This modification should allow a brighter control room environment.

3. The new 23-inch CRT, as modified above, can serve as a direct replacement for the present-type 23-inch CRT without posing any serious installation or operational problems.

4. In the one test in which a violent implosion was achieved on a CRT incorporating the Chemcor/Lexan front panels (no Kimcode), the panels did not break. This indicates the Chemcor/Lexan combination of panels was an effective safety barrier.

RECOMMENDATIONS

From the conclusions, it is recommended that:

1. Field evaluations of production units from future vendors of the 23-inch antireflective cathode-ray tube (CRT) should be conducted at en route centers. The display resolution and antireflectivity of these tubes, under actual control room lighting, should be required to at least equal those qualities of the developmental tubes tested by NAFEC and approved by the Air Traffic and Airway Facilities Services.

2. Potential contractors of the 23-inch antireflective CRT should be briefed on the optical performance and safety requirements intended for the FAA specification of the new tube (FAA-E-2573 B). Potential vendors should especially be required to furnish statistical proof of product safety by subjecting sample tubes from their initial production lots to implosion-inducing tests. These tests would verify the individual protective functions of the faceplate and rimband modifications and should be performed at the contractor's plant or at the NAFEC CRT test facilities.

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7. MIL-STD-1311, TEST METHODS FOR ELECTRON TUBES, U.S. Department of Defense, Washington, D.C. 20301.

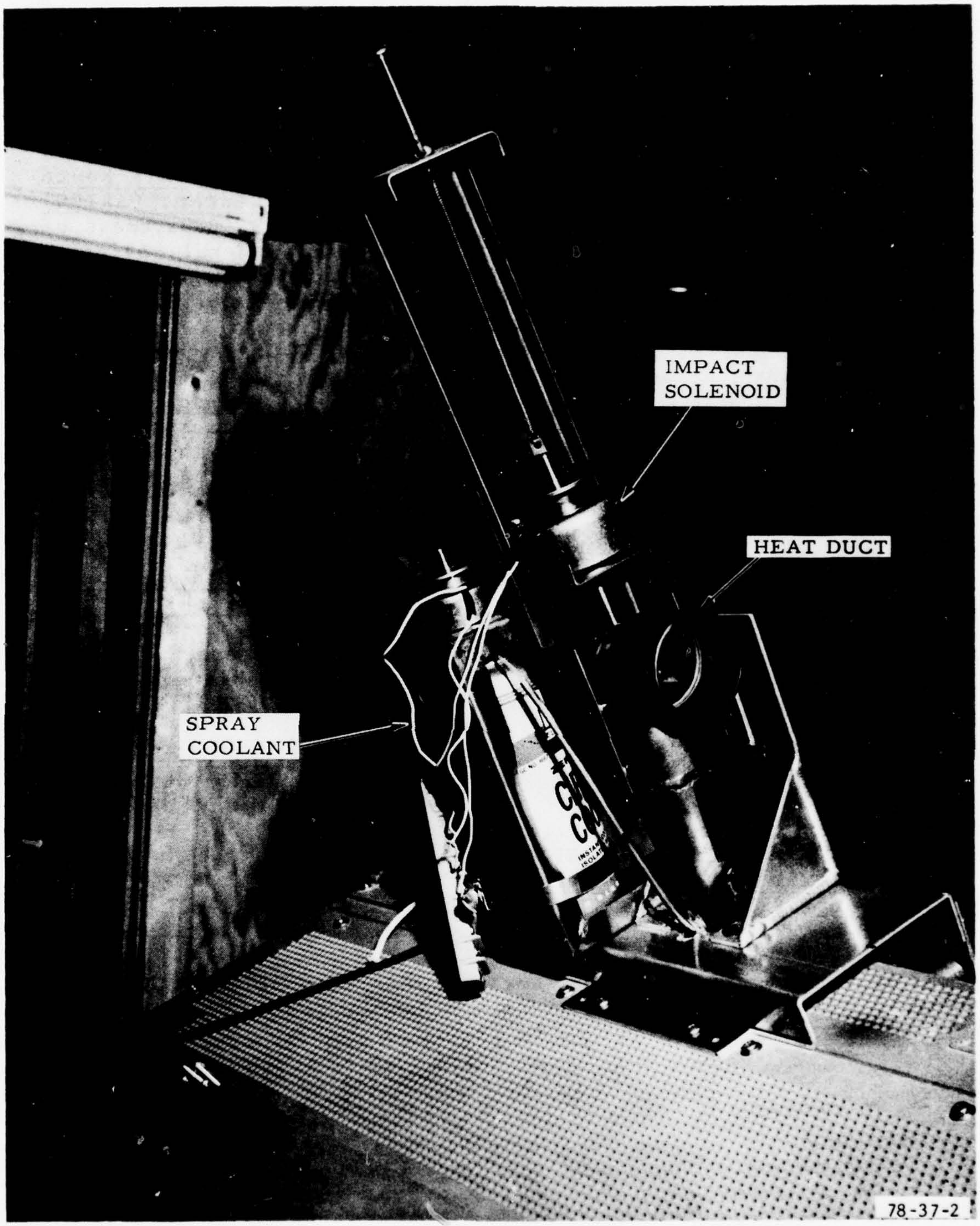


FIGURE 1.   ORIGINAL IMPLOSION-INDUCING DEVICE

A. FRONT VIEW

B. SIDE VIEW

FIGURE 2. EFFECTS ON ORIGINAL-TYPE OUTER VIEWING SURFACE CAUSED BY IMPLOSION OF ORIGINAL-TYPE CRT

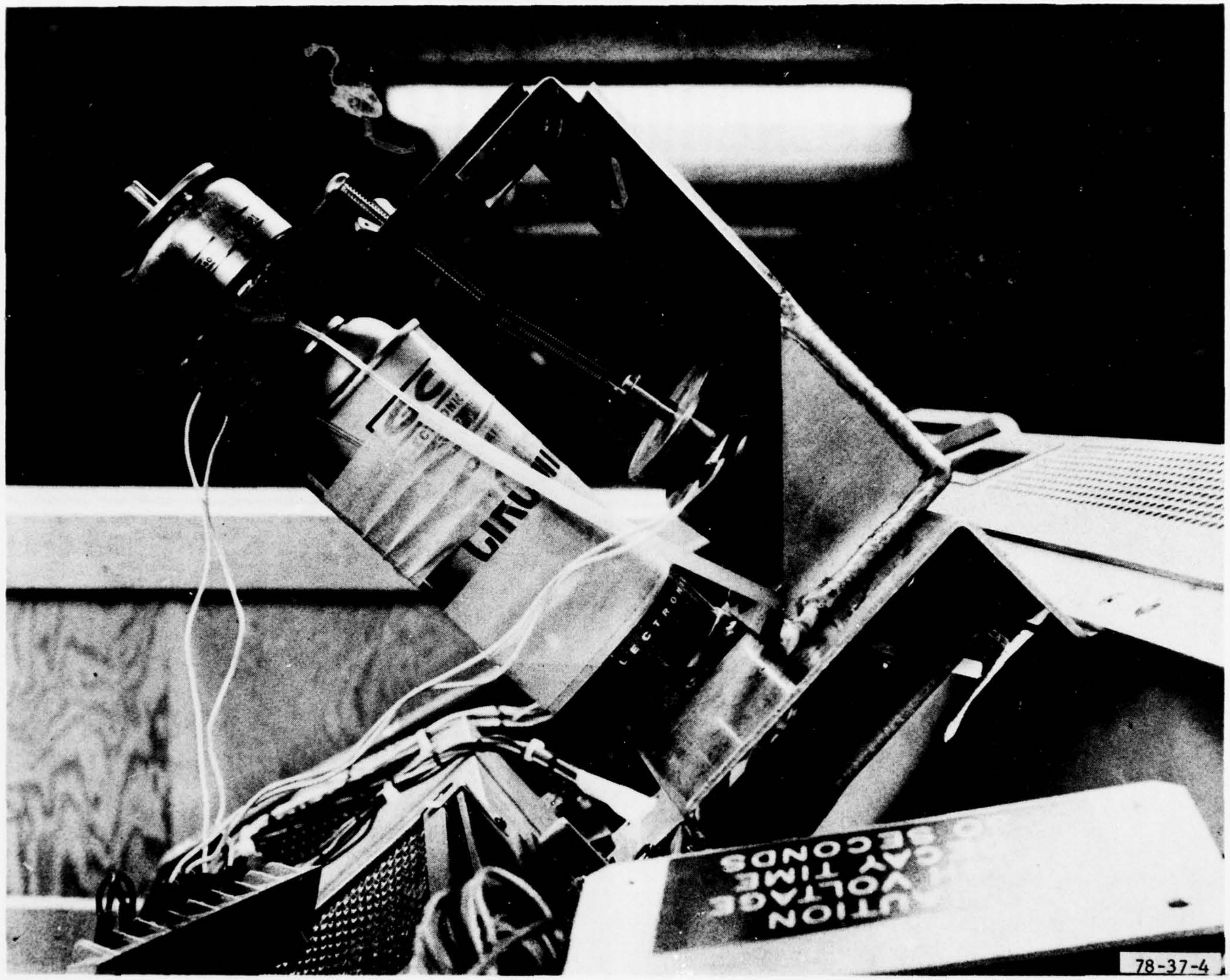


FIGURE 3. MODIFIED VERSION OF ORIGINAL IMPLOSION-INDUCING DEVICE

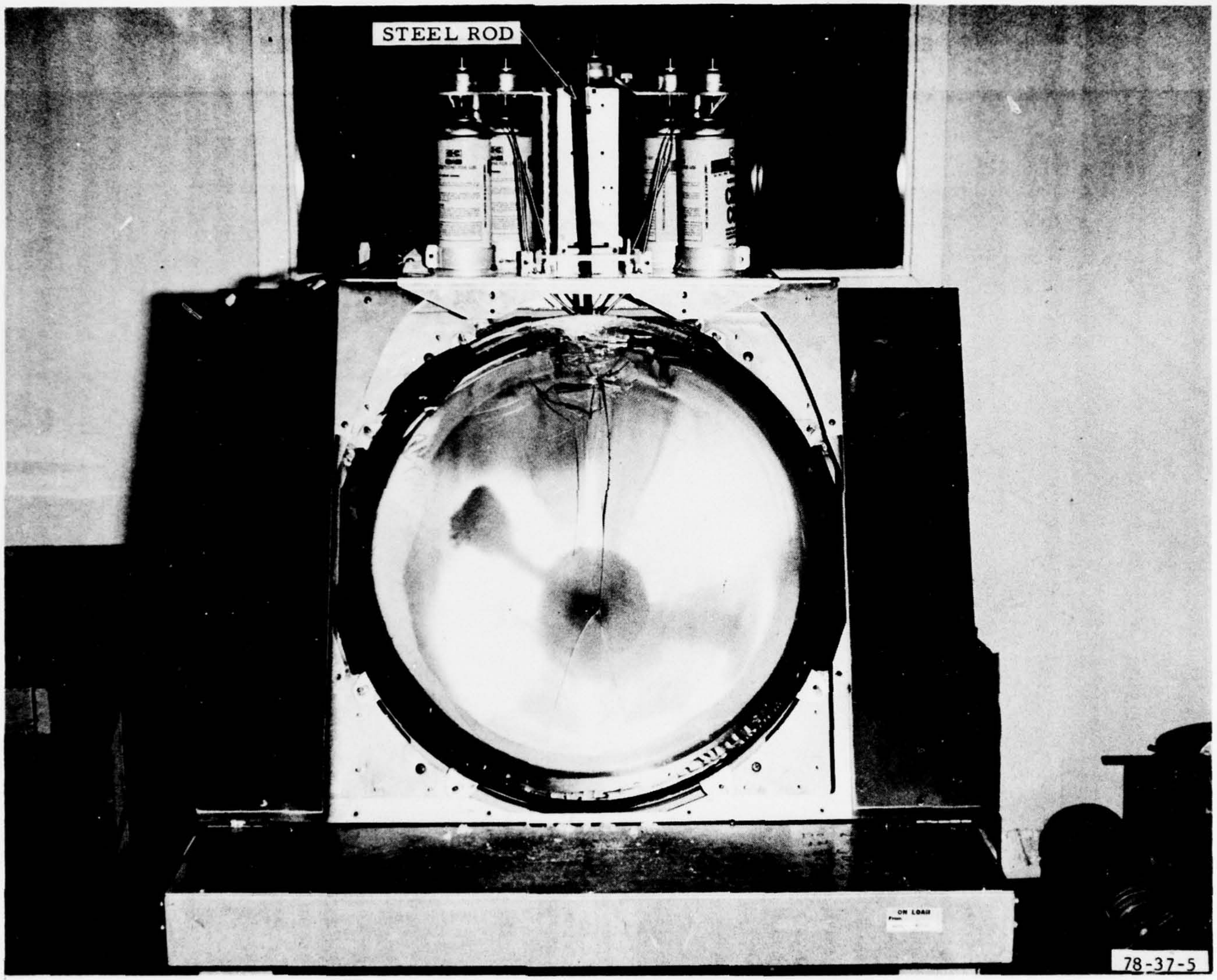


FIGURE 4. IMPLOSION-INDUCING SYSTEM FOR FINAL TESTS

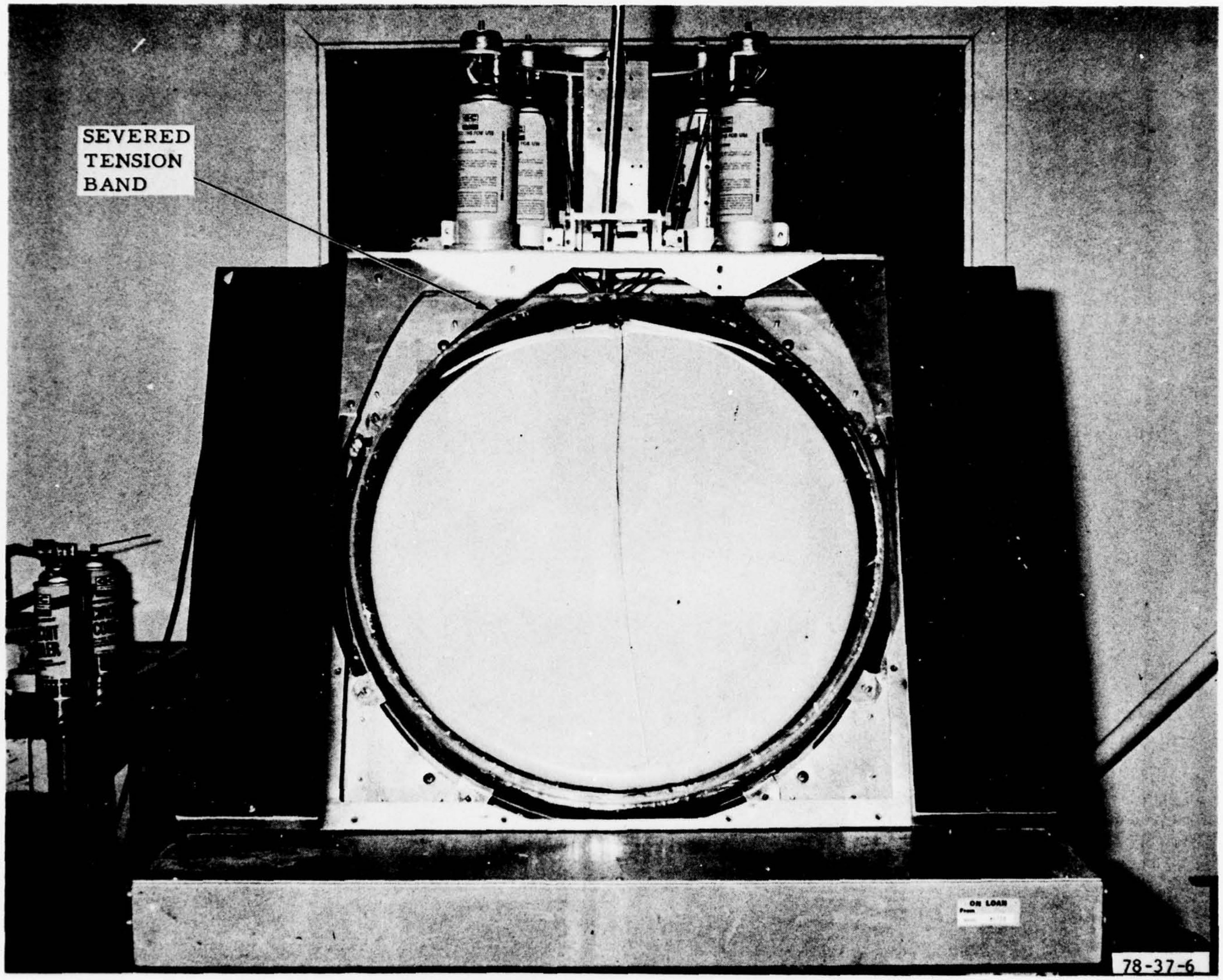


FIGURE 5. PUNCTURED CRT WITH SEVERED TENSION BAND

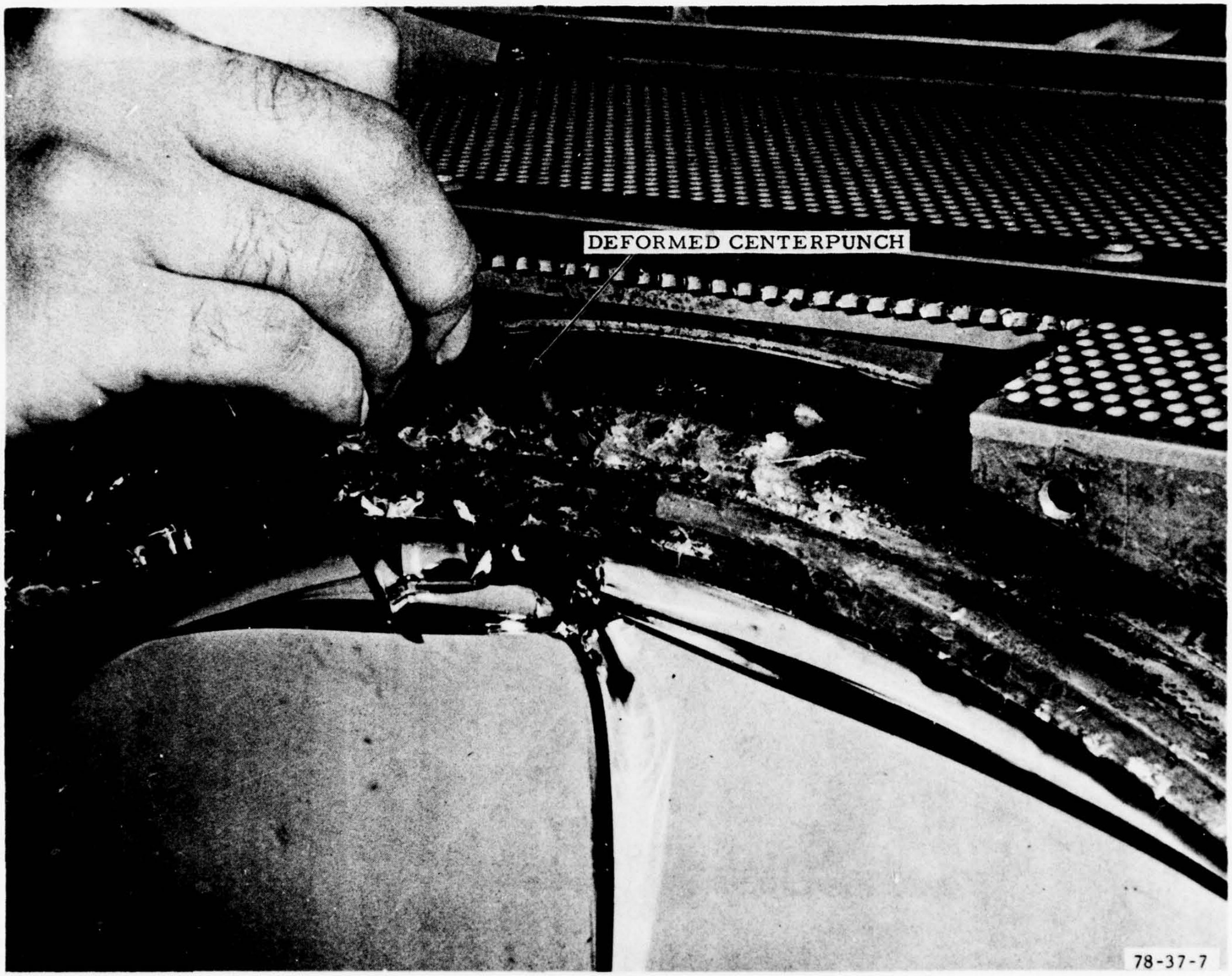


FIGURE 6. CLOSEUP OF CRT STEEL SHELL WITH DEFORMED CENTERPUNCH

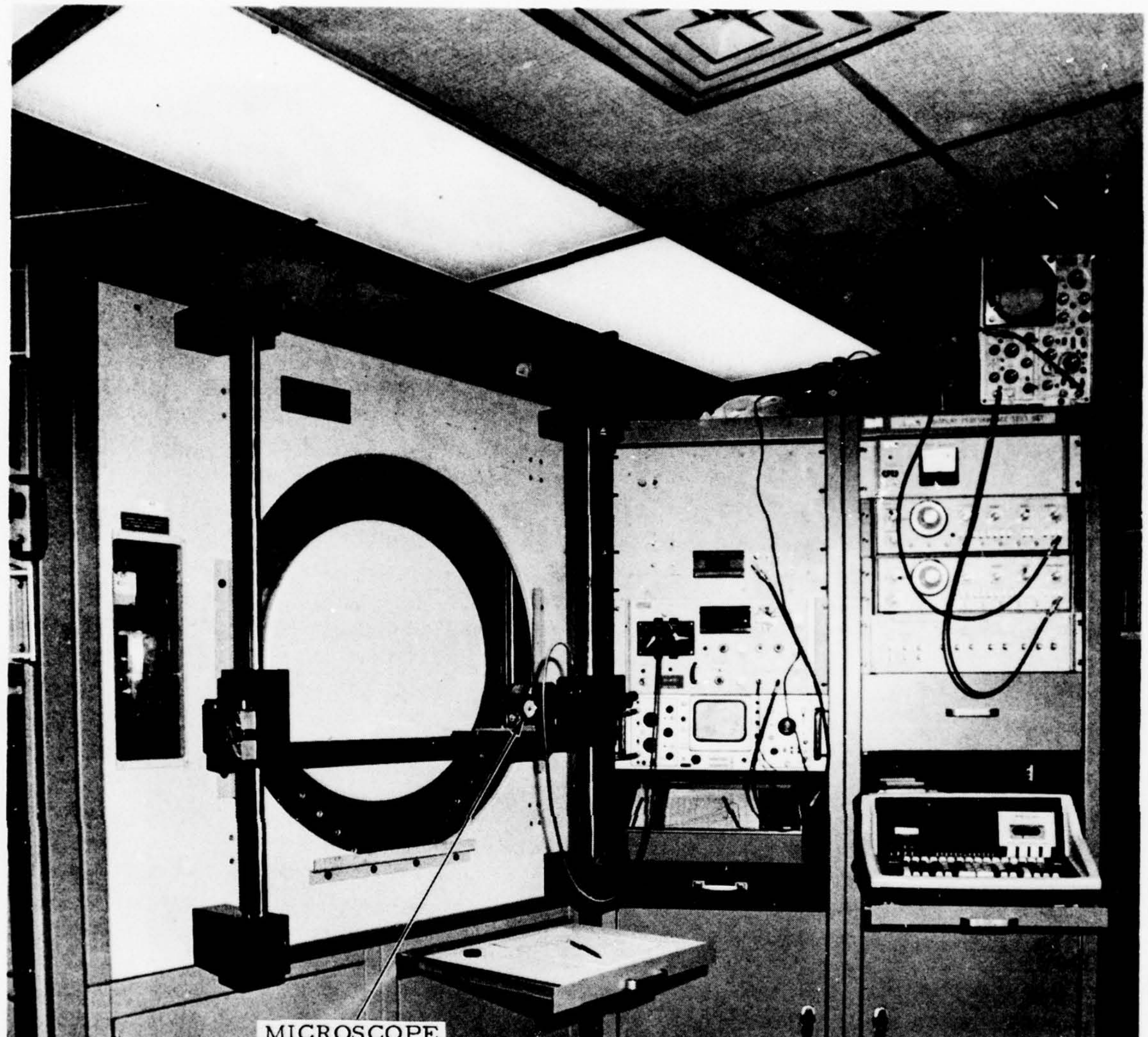


FIGURE 7. TEST SET: BRIGHTNESS MEASUREMENT CONFIGURATION

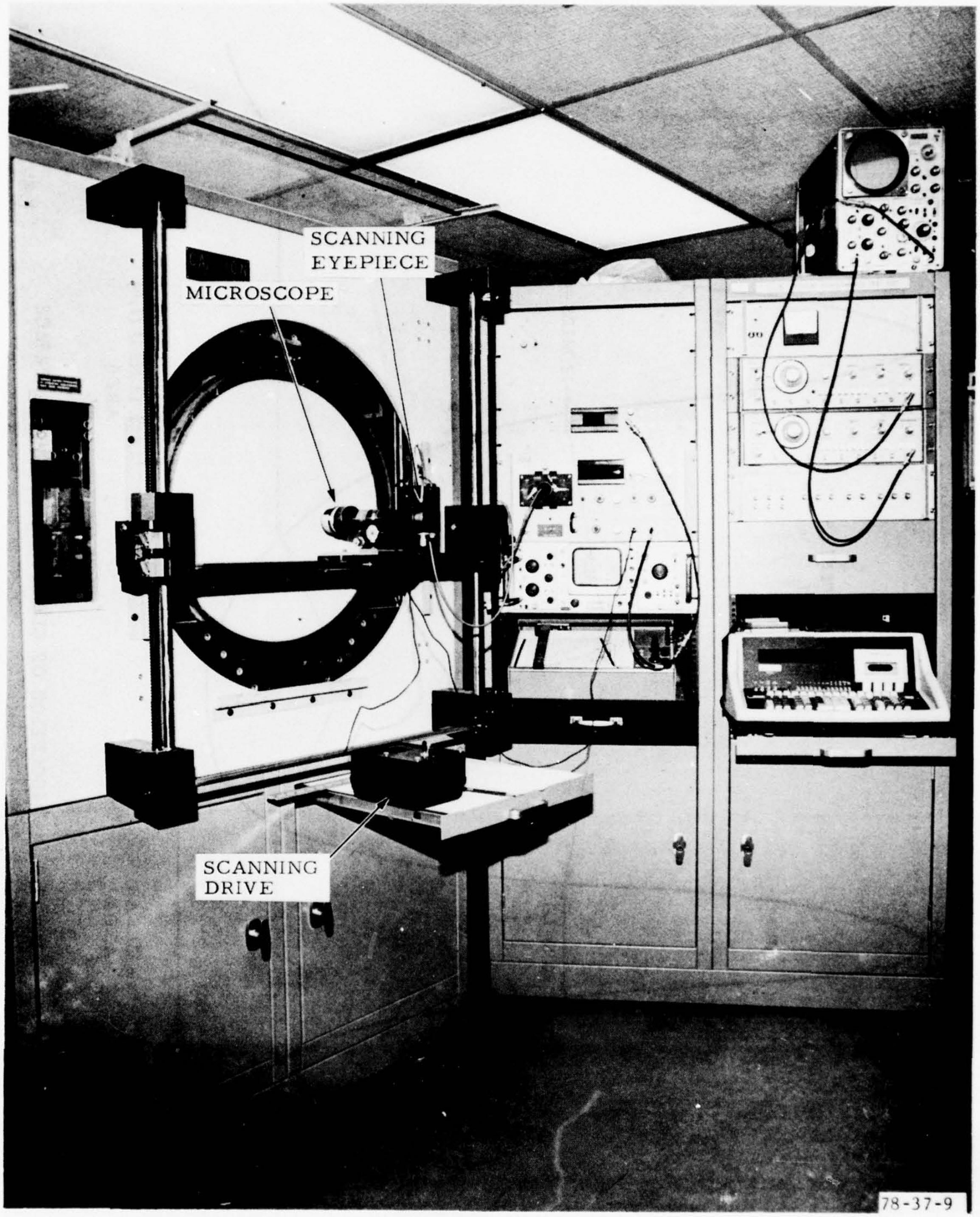


FIGURE 8. TEST SET: LINEWIDTH MEASUREMENT CONFIGURATION

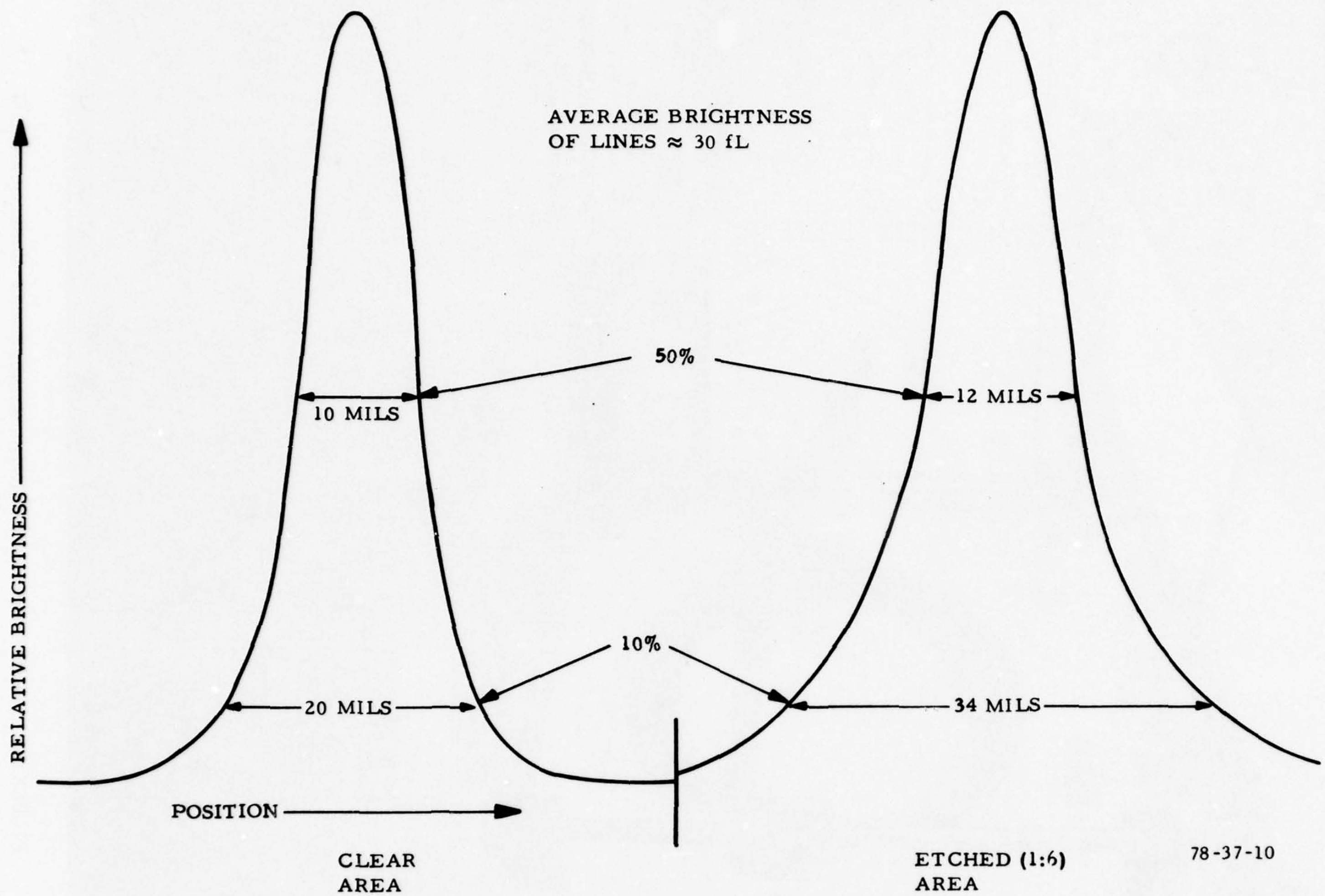


FIGURE 9. RESOLUTION OF CLEAR VERSUS ETCHED SURFACE

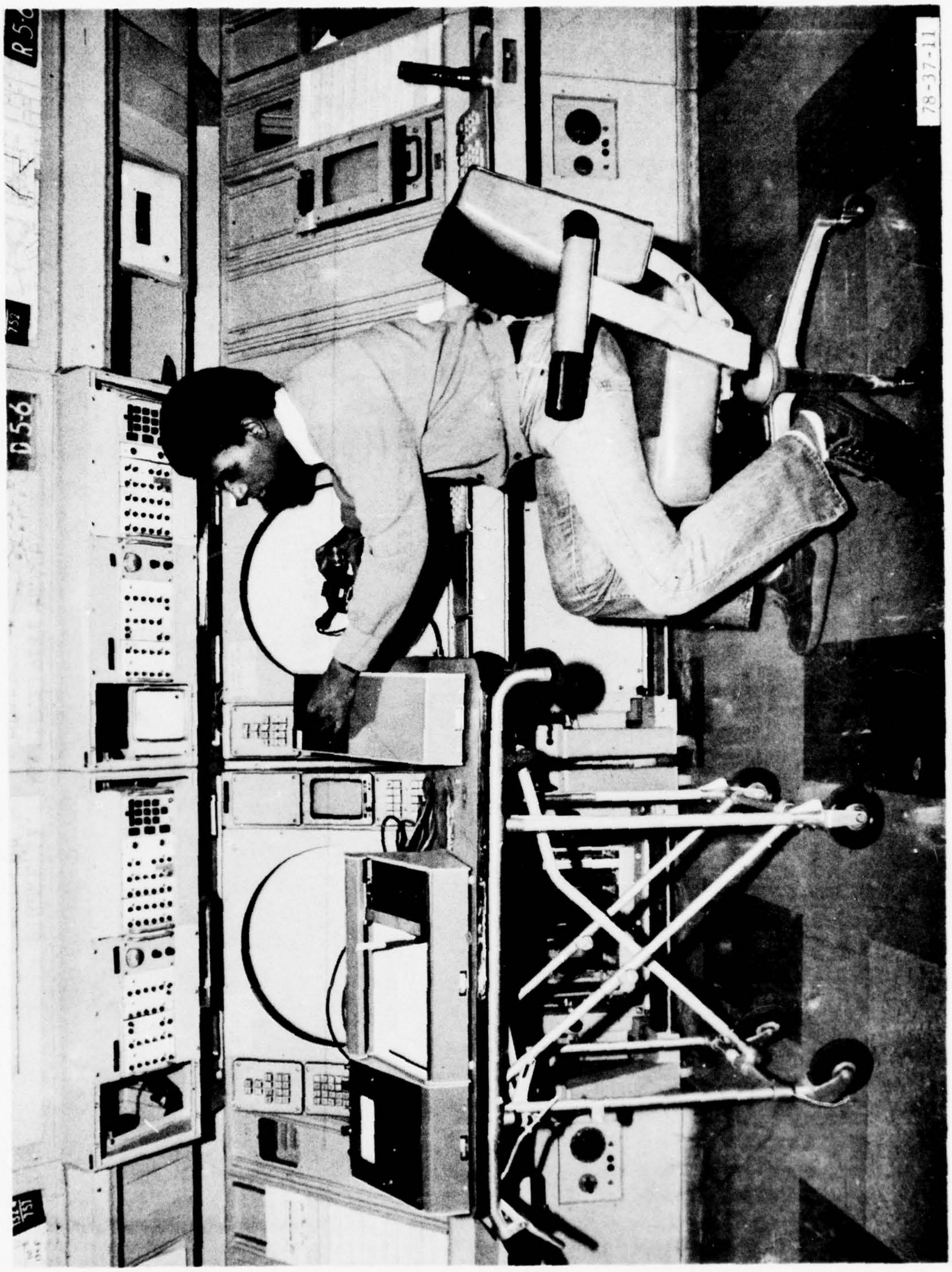


FIGURE 10. SPECTROREFLECTIVITY MEASUREMENT SYSTEM

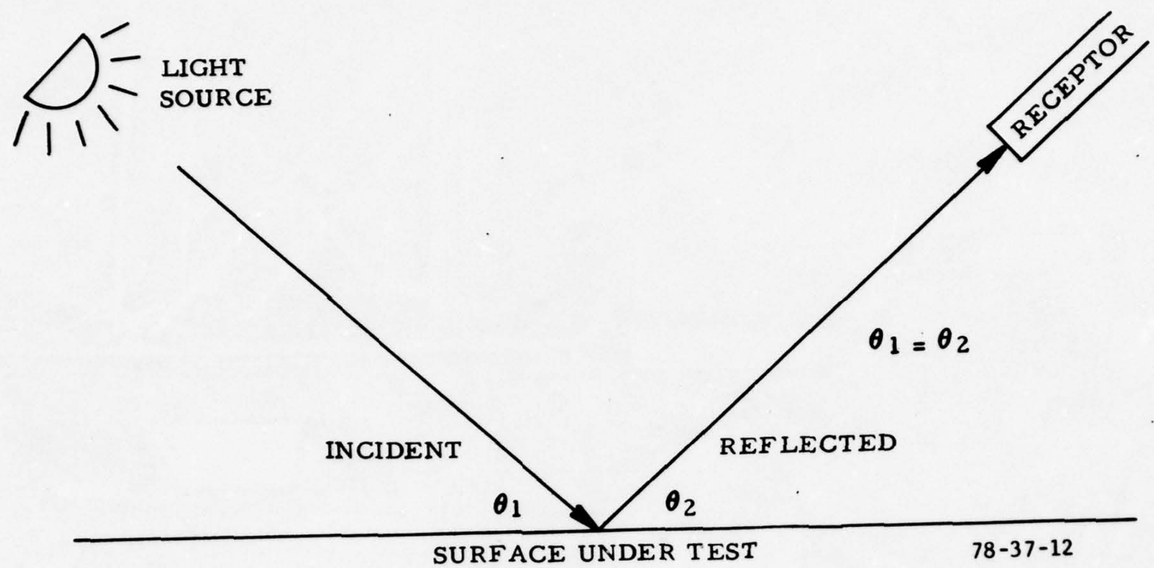


FIGURE 11. REFLECTIVITY MEASUREMENTS

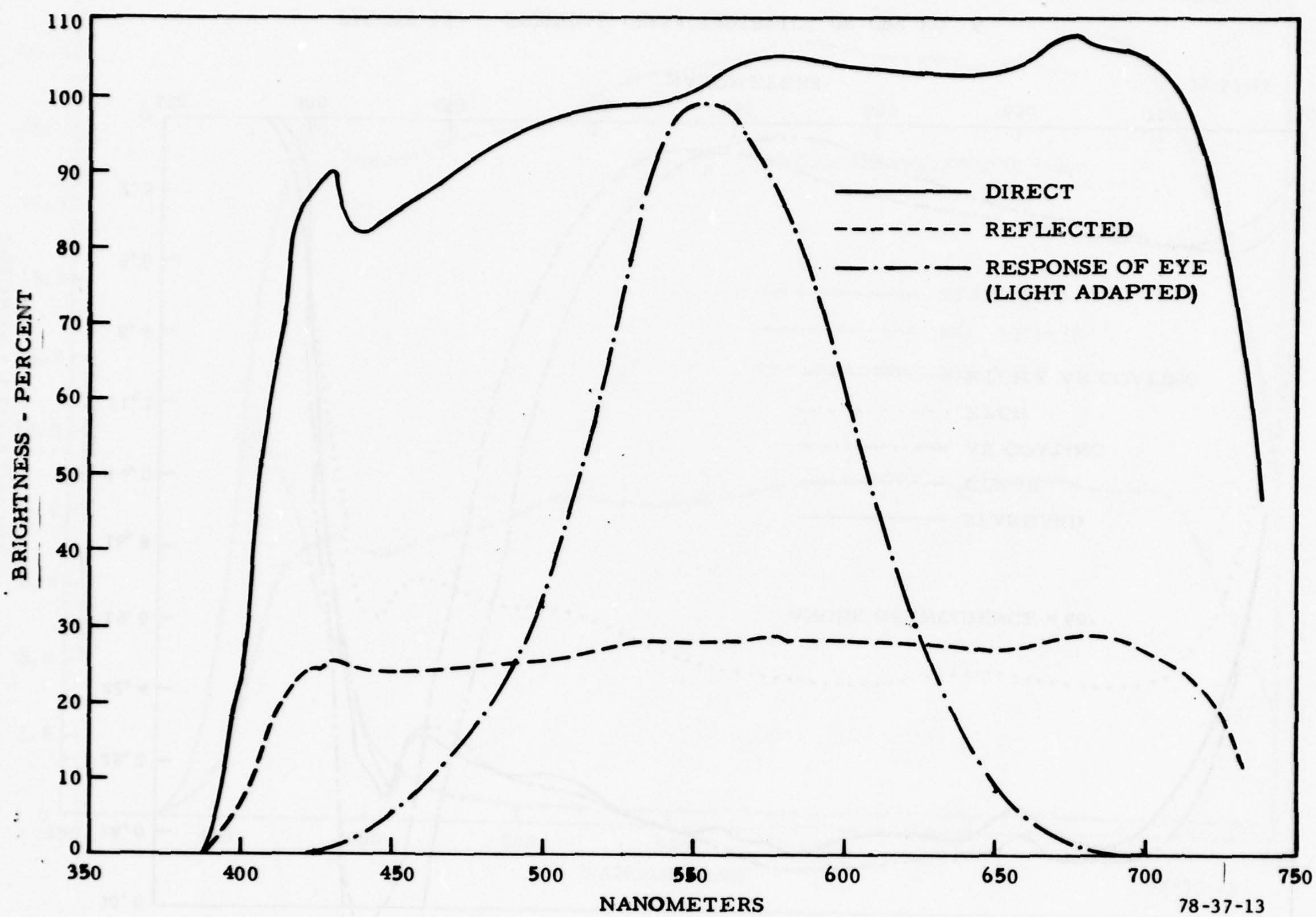


FIGURE 12. SPECTRAL CHARACTERISTICS OF REFLECTOMETER LIGHT SOURCE

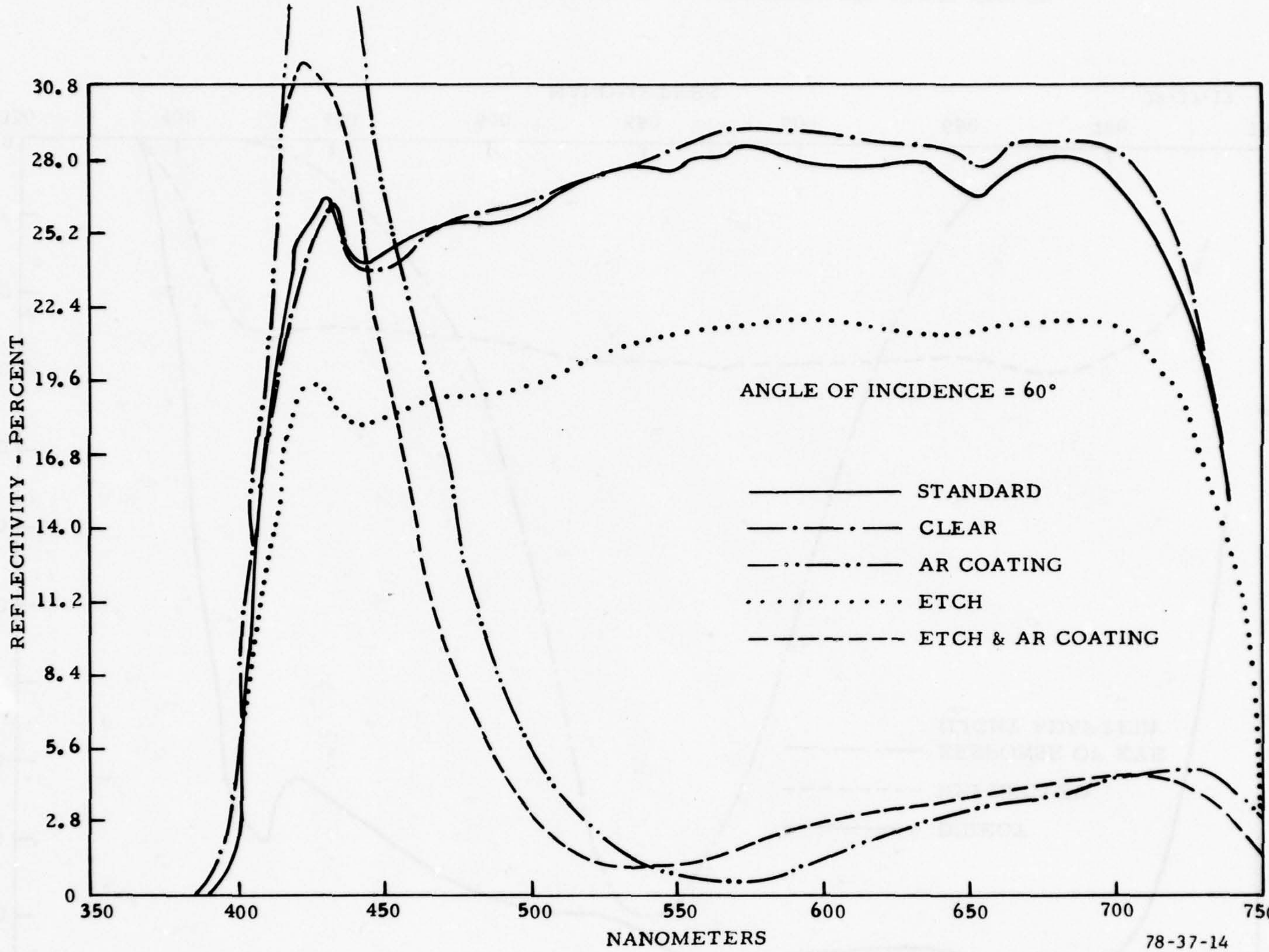


FIGURE 13. SPECTRAL CHARACTERISTICS OF CRT NO. 6

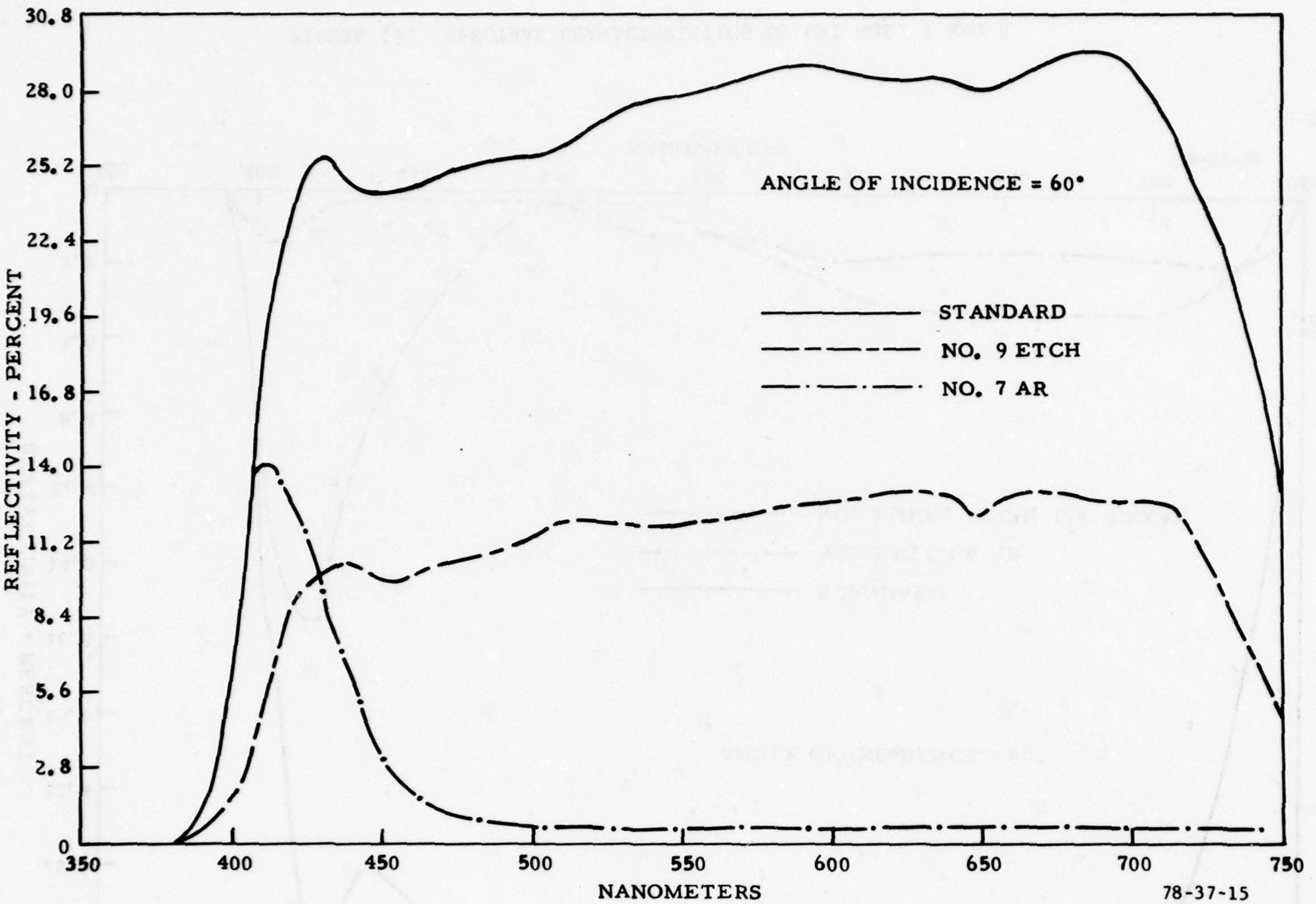


FIGURE 14. SPECTRAL CHARACTERISTICS OF CRT NOS. 7 AND 9

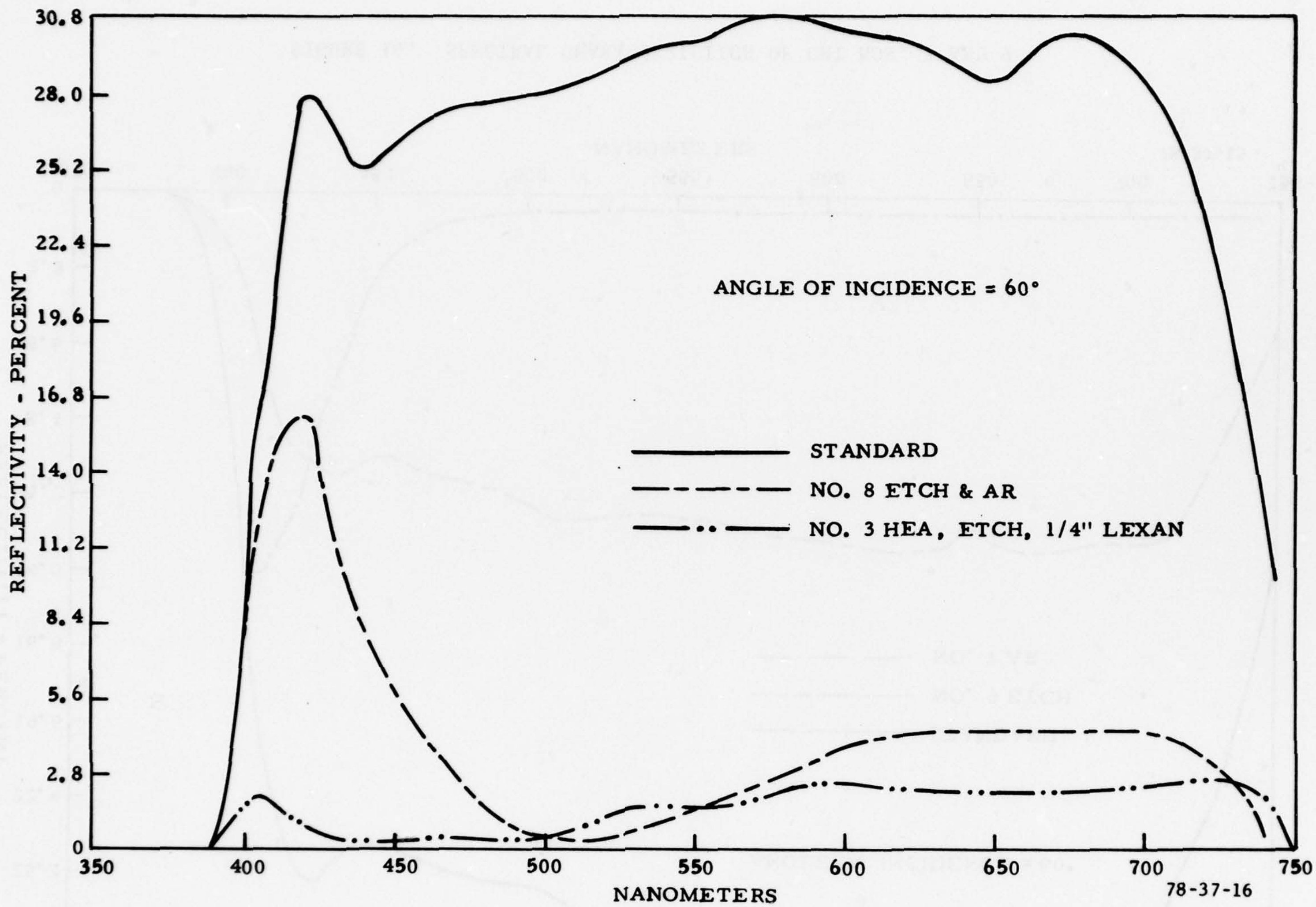


FIGURE 15. SPECTRAL CHARACTERISTICS OF CRT NOS. 3 AND 8

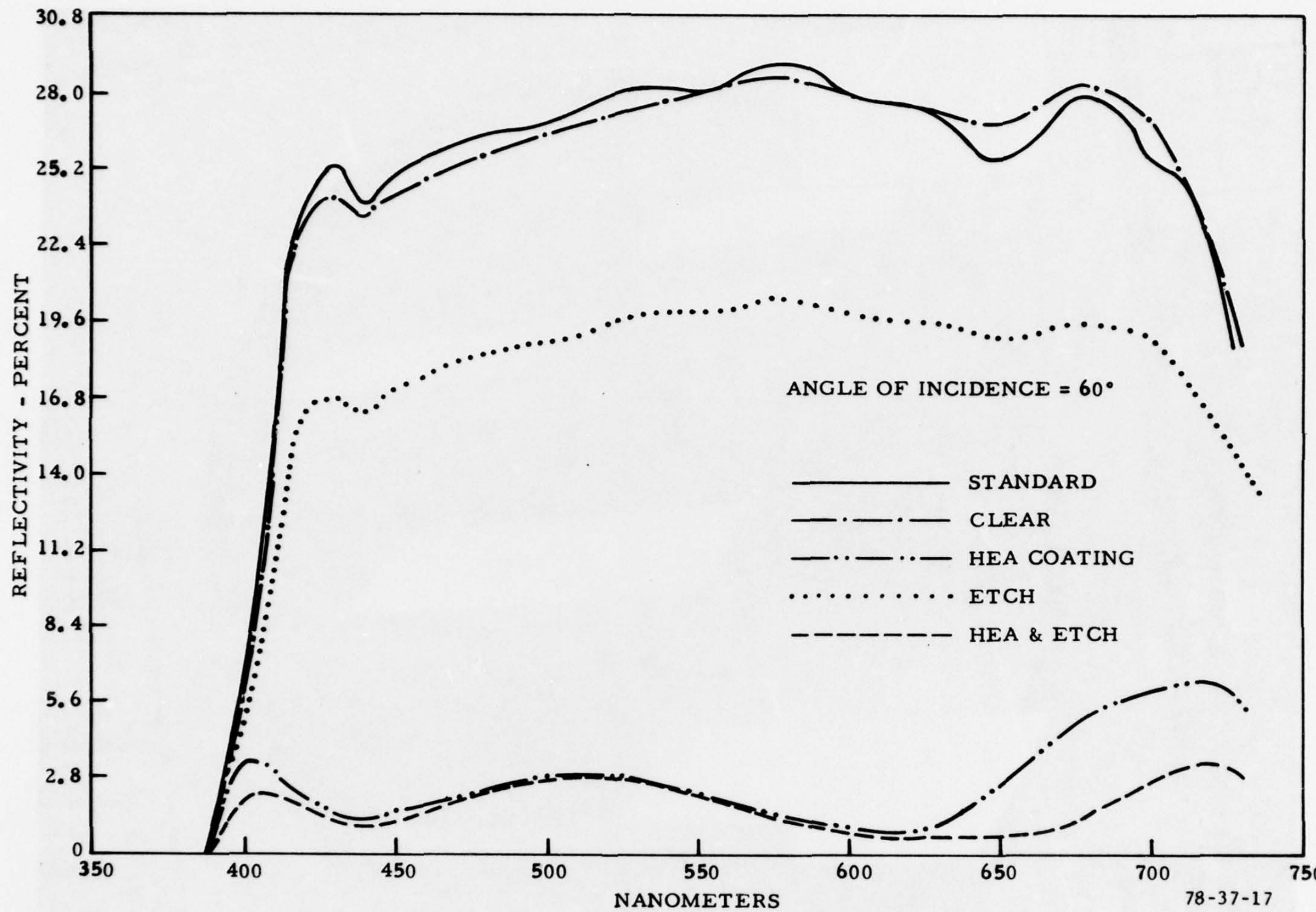


FIGURE 16. SPECTRAL CHARACTERISTICS OF CRT NO. 10

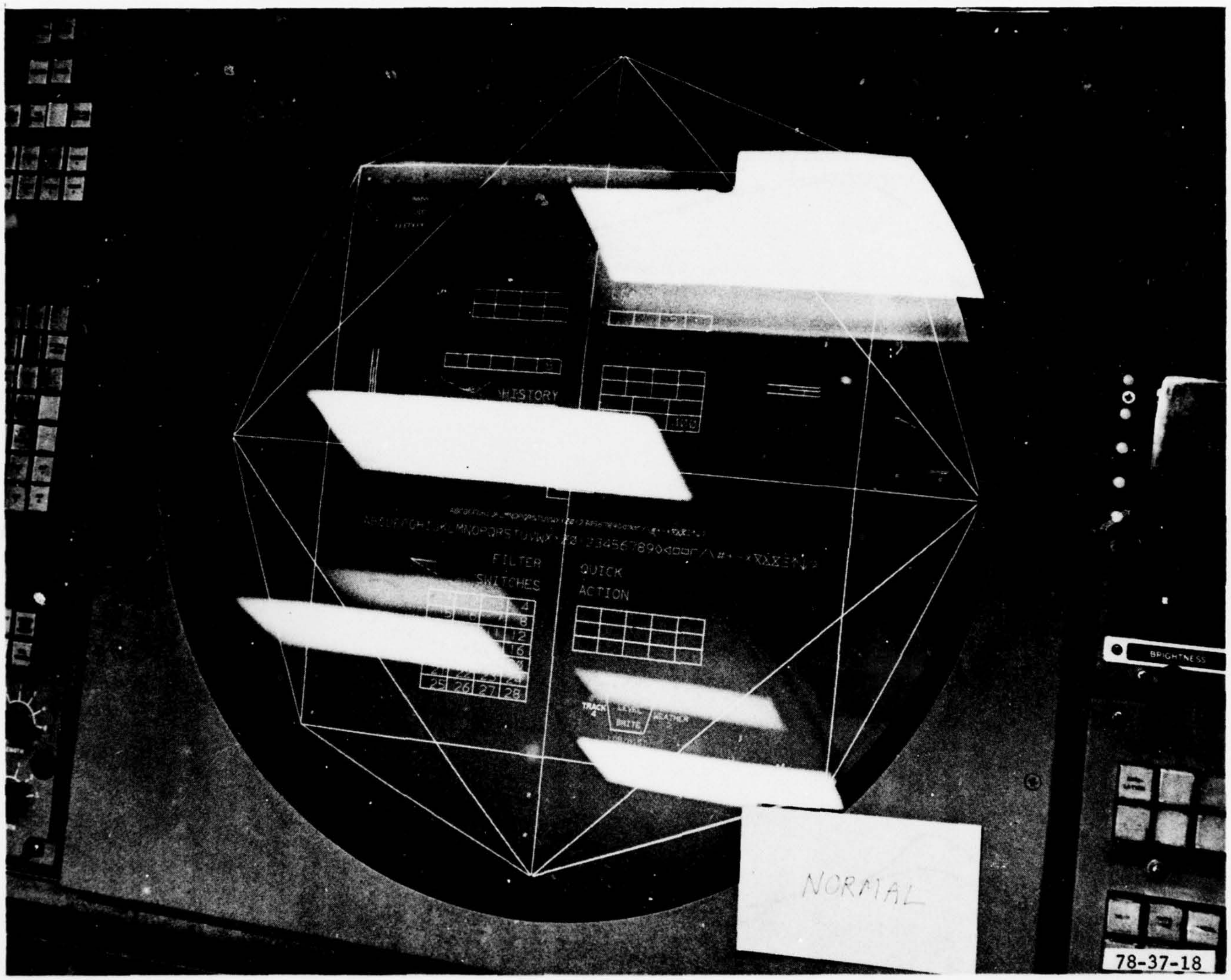


FIGURE 17. REFLECTIONS FROM NORMAL DISPLAY

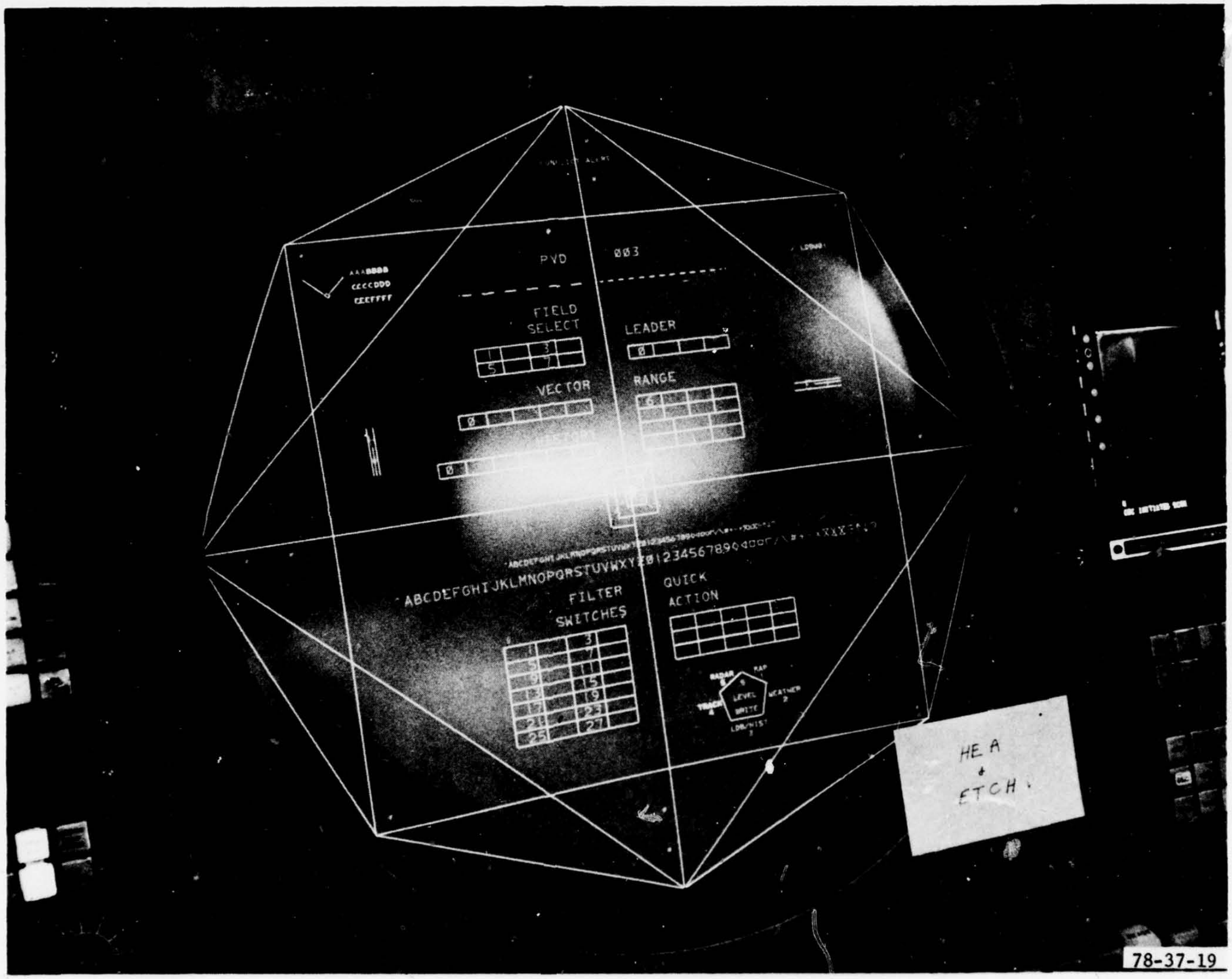


FIGURE 18. REFLECTIONS FROM NEW DISPLAY

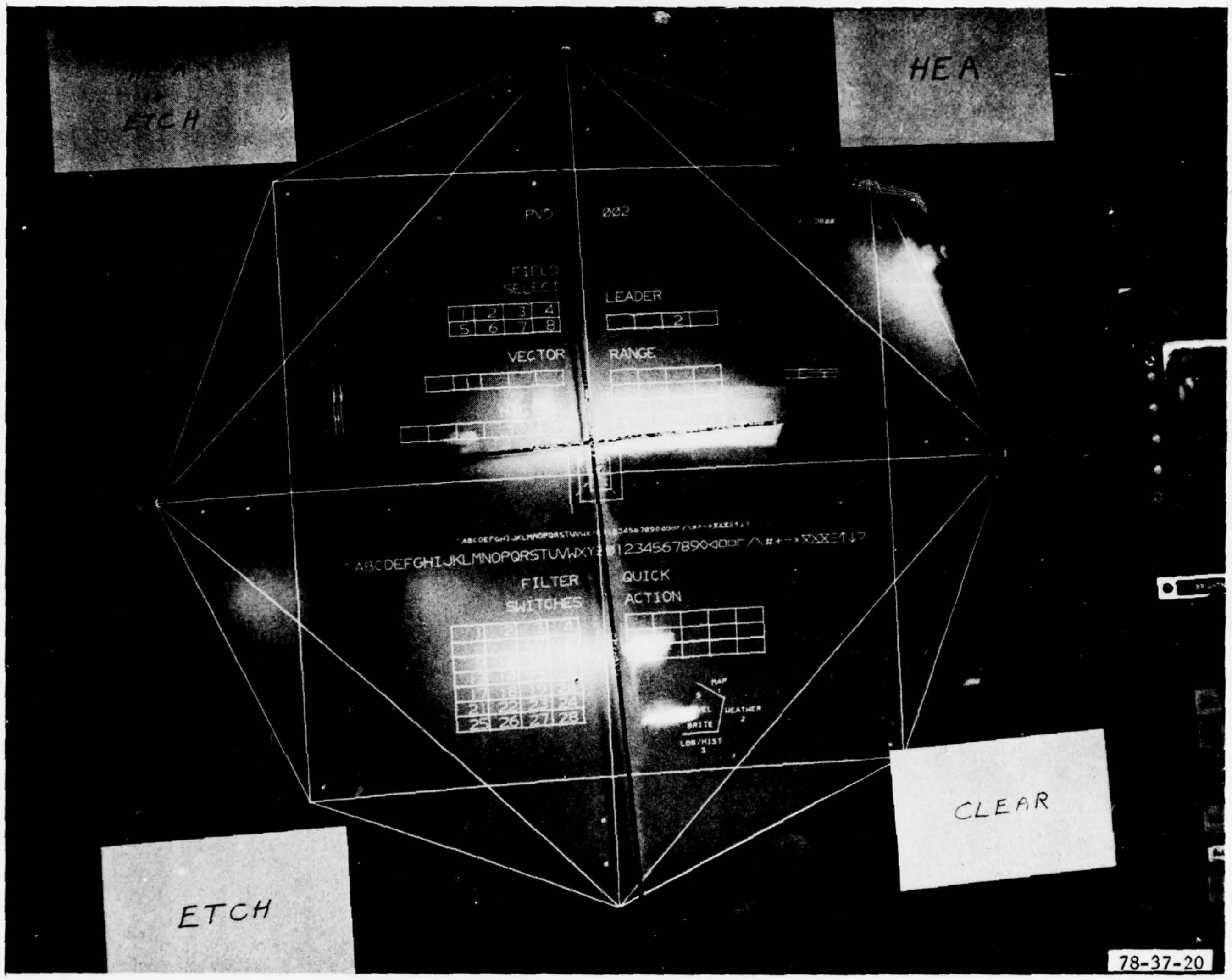


FIGURE 19. REFLECTIONS FROM FOUR-SECTION DISPLAY

APPENDIX A

EXCERPTS FROM FINAL REPORT "CATHODE-RAY WITH MODIFIED FACEPLATE PROTECTION AND ANTIREFLECTIVE FEATURES

FINAL REPORT AND DOCUMENTATION

FOR

FAA CONTRACT NO. DOT-FA76NA-3029

CATHODE RAY TUBES WITH MODIFIED FACEPLATE PROTECTION AND ANTI-REFLECTION FEATURES

PREPARED FOR

FEDERAL AVIATION ADMINISTRATION
NAFEC
ATLANTIC CITY, NEW JERSEY

JULY 1978

PREPARED BY

CHARLES M. HALL
ATC DIRECTORATE, EQUIPMENT DIVISION
WAYLAND, MASS. 01778

AND

MICROWAVE AND POWER TUBE DIVISION
INDUSTRIAL COMPONENTS OPERATION
QUINCY, MASS. 02169

RAYTHEON COMPANY
EQUIPMENT DIVISION

FINAL REPORT

Background

This development contract was part of a continuing effort by the FAA to arrive at a satisfactory method of CRT reflection reduction which will allow the general lighting level in the Air Route Traffic Control Center (ARTCC) operations areas to be raised. Presently the aisle illumination levels in most centers is adjusted as low as 0.13 foot-candles (very dim) to 0.75 foot-candles because higher lighting levels cause specular reflections to appear on the PVD cathode ray tube and safety glass surfaces. Some Controllers have complained that the reflections are distracting and are causing visual fatigue. Previous related work performed by Raytheon under contract to the FAA included a development program to inject light into the CRT face panel to illuminate the phosphor, thus raising the display background level which tended to mask reflections from the outside glass surface. The results of that effort are described in Report No. FAA-RD-76-46. Another related Raytheon contract was for a study of the Boston ARTCC operations area general lighting conditions and the sources of PVD screen reflections. Recommendations were made for modifications to the various sources of reflecting light and are contained in Report No. FAA-RD-76-203. In parallel with the above programs Raytheon, under separate contracts, furnished small quantities of cathode ray tubes to the FAA with experimental bonded panels including Lexan polycarbonate only and glass only. The panels were variously treated for reflection reduction by etching or with quarter wave coatings or combinations of both. Some CRT's were furnished with G.E. Lexguard bonded to the faceplate. This material which has a three-part sandwich construction with Lexan in the center and glass on both sides had two major drawbacks. It could not be sagged to conform to the CRT faceplate curvature and the G.E. assembly of glass and Lexan had a propensity to delaminate. The FAA performed induced implosion tests on some of the special tubes and discovered that Lexan provides good operator protection in case of an implosion. It was these tests that led to the contract for combining separate layers of Lexan and anti-reflection treated glass onto the faceplates of 23-inch CRT's.

Description of Work Performed

Raytheon has delivered to NAFEC all of the cathode ray tubes required by FAA Contract No. DOT-FA76NA-3029 and Modifications 1, 2, and 3 thereof. The specially configured 23-inch diameter CRT's with modified implosion protection and anti-reflection features were basically Raytheon Type CK1498P31 tubes that included various combinations of Lexan polycarbonate plastic and anti-reflection treated glass fastened to the manual CRT faceplate. Most of the CRT's also included a Kimcode-type rimband for implosion prevention. The development contract, which included three contract modifications, was continually changing in scope as the various CRT's were evaluated. As soon as finished tubes were available at Raytheon and were accepted at the manufacturing plant by the FAA they were shipped to NAFEC for evaluation in Plan View Displays. The subsequent direction of the contract was determined by the NAFEC evaluations which took place in an environment similar to an enroute ARTCC. The first items delivered included a layer of polycarbonate and a layer of glass, etched and anti-reflection coated, over the faceplate which proved to be too thick. The outside etched surface, nearest the operator, was too far from the CRT phosphor and, as a result, caused the displayed characters and symbols to be diffused to a degree which was unacceptable. As the program progressed the panels were made thinner and the etch was made finer. The final product, which very satisfactorily eliminated glare and specular reflections from the CRT surface (which was the program's objective), included a 1/8-inch layer of Lexan bonded to the CRT and a 0.05 inch layer of Chemcor, Corning Glass Works chemically tempered glass, bonded to the Lexan. The combination was thin enough so the characters were not diffused by the etch and the Chemcor glass provided a tough outside surface which could be etched and coated with an anti-reflection quarter wave coating and which would not scratch and wear under normal use as the polycarbonate layer would.

Implosion prevention features were also built into the CRT assembly because in order to take advantage of the anti-reflective panel the present PVD safety "glass" (3/8-inch Lexan panel), mounted separately from the tube to the PVD bezel, has to be removed since it is a reflecting surface.

Implosion prevention on the tubes furnished with the Kimcode-type rimbands consists of a three part system. First is a conformal steel hoop (rimband) around the perimeter of the CRT face. The hoop overlaps the edge of the face panel and the face panel shoulder, and is epoxyed into place just prior to another circumferential tension band being applied over the hoop. Thus the CRT panel is held in compression and, because of its own thickness, resists breaking inward should a crack occur in the face panel structure.

The second part of the system is the panel of 1/8-inch thick polycarbonate plastic bonded to the CRT face panel. This plastic provides impact and scratch protection for the panel and, in case of a potential implosion due to a crack traveling into the faceplate area, restricts the air supply necessary to support the implosion. The failed CRT will gradually fill with air and the high vacuum will be neutralized. If, by chance, the CRT does implode, the polycarbonate panel will act as a barrier to the large pieces of glass which could otherwise be thrown forward toward the controller.

The third feature of this system is the layer of thin, chemically tempered glass that is bonded to the outside of the polycarbonate panel. The glass provides a surface which can be treated for anti-reflection and which resists scratches and abrasion during normal use to a much higher degree than polycarbonate can.

A total of 21 tubes in various configurations were delivered against the three contract modifications as described below and in the table following. Eight attachments to this report include supporting data and photographs of the final product as well as the documentation required (Attachment 8) as part of the basic contract.

<u>Modification 1, Two Items Delivered</u>

Item 1; A CK1498P31 CRT with the normal tension band and mounting brackets but with a nominal 0.25-inch thickness of 68 percent transmittance light green Lexan bonded to the CRT faceplate and a nominal 0.188-inch thickness of etched clear glass bonded over the Lexan. The glass panel was

etched such that one third of the panel had a 1:6 etch, another third a 2:5 etch and the center third was left clear. The method used for determining the degree of etch is included herein as Attachment 3.

Item 2; A CRT with the normal tension band, mounting brackets, fiberglass boot, 0.25-inch thick clear Lexan, and an outer 0.188-inch thick glass panel with one-third etched with a 2:2 band, one-third etched with a 2:6 band and the center third clear. An Optical Coating Laboratories, Inc. (OCLI) high efficiency anti-reflective (HEA) coating was applied to half of the panel 90° to the etched bands. The result was a six section panel which provided all possible combinations for evaluation. Attachment 1 includes photographs of the results obtained by the various combinations above.

At this point it was jointly decided between the FAA and Raytheon to change the course of the program to provide some CRT's with thinner protective Lexan/glass panels and some with the thicker panels. The reason was it appeared that the distance of the etched surface from the phosphor was too large thus causing the displayed characters to appear diffused, even when the etch was very fine. This change in direction led to contract modification 2. It was also decided to make the facepanel components as clear as possible so the contrast ratio would actually be reduced. Earlier experiments with the CRT phosphor illuminated (contrast ratio reduced) indicated the lighter background helped to decrease the effect of reflections by washing them out. Also, the lighter background provided a more restful display because the displayed image did not appear as bright lines and characters floating without reference against a black background.

<u>Modification 2, Eight Items Delivered</u>

Item 1; A CRT with Kimcode-type rimband, mounting brackets, fiberglass boot, 0.25-inch thick clear Lexan panel and outer 0.188-inch thick clear glass with anti-reflection coating and no etch.

The Kimcode-type rimband is a stainless steel hoop which is applied to the CRT faceplate shoulder and held in place with an outer tension band and epoxy. The rimband and tension band as they appear on a CRT are illustrated in Attachment 2. All rimbands had a one-inch hole drilled at a point defined by the FAA

which aligned with the CRT shoulder. The hole was to allow access to the glass in the area of highest strain in case it was desired to induce an implosion by impacting the glass with a steel rod.

Item 2; A CRT with Kimcode-type rimband as above with a 0.25-inch clear Lexan and a 0.188-inch clear glass very finely etched without anti-reflection coating.

Item 3; A CRT with Kimcode rimband as above with 0.25-inch clear Lexan and a 0.188-inch clear glass with very fine etch and anti-reflection coating.

Items 4, 5, and 6 included the CRT and Kimcode rimband as described in Item 1 but had Lexan panels nominally 0.125-inch thick and an outer panel of Corning Chemcor chemically tempered glass nominally 0.05-inch thick. This combination provided a very thin protective panel assembly. The Chemcor was very finely etched (approximately 3:1) and anti-reflection coated. Chemcor glass is described in Attachment 4 which is a Corning Glass Works paper titled "The Versatile Properties of Chemically Strengthened Glass".

Item 7 was a CRT as above with the thin Lexan and Chemcor panel combination. The Chemcor was treated with anti-reflection coating only (no etch).

Item 8 was a CRT with thin Lexan and Chemcor panels as above but with half of the Chemcor panel etched to approximately 3:1 and half of the panel left clear. The combination panel was then coated with an anti-reflective treatment at right angles to the etch/clear sections thus providing a four section panel with four different surfaces for evaluation ranging from the plain glass surface to the etch plus AR coating combination.

Modification 3, Eleven Items Delivered

Because of the promising reflection test results obtained with CRT's shipped against contract Modifications 1 and 2 the FAA ordered 11 additional CRT's under Modification 3. These tubes were to all have Kimcode-type rimbands, 1/8-inch Lexan and 0.05-inch Chemcor panels with the Chemcor very finely etched. The intention was to use the tubes for induced implosion tests at NAFEC to prove the integrity of the new design. New tubes with all of the improvements were desired for implosion testing so a known configuration

baseline would be maintained. A number of previous FAA induced implosion tests had been performed using Raytheon 23-inch tubes so a confidence level had been established.

Raytheon delivered all of the 11 CRT's as specified with the exception of the last two which included, at the request of the FAA and at no additional cost, OCLI HEA coating on the Chemcor panels.

Conclusion

In summary, either of the thin panel configurations, either etched only or etched with anti-reflection coating may be sufficient for use in FAA Centers. Tests have indicated the original objective of raising the control room ambient light level while reducing reflections from the CRT surface appears to have been met. If the previous Raytheon recommendations for reducing the specular light sources at FAA Enroute Centers are adopted in conjunction with the installation of a version of the anti-reflection CRT's it is felt the overall room lighting problem will be solved.

The following table is a compilation of the anti-reflection CRT's delivered by serial number and configuration.

SUMMARY OF
ANTI-REFLECTION CRT CONFIGURATIONS DELIVERED
CONTRACT NO. DOT-FA76NA-3029

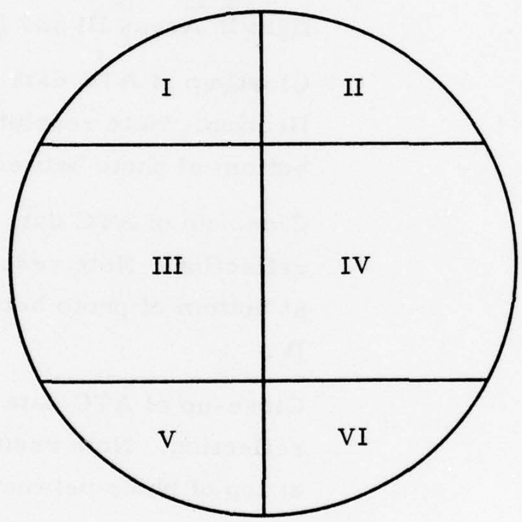
Modification	Serial No.	Lexan	Glass	Etch	Degree of Etch	AR Coating	Implosion Protection
1	1	1/4", 68%, Green	3/16" Plate	2/3 Etch, 1/3 Clear	1:6, 2:5	None	T-Band
	2	1/4" Clear	3/16" Plate	2/3 Etch, 1/3 Clear	2:2, 2:6	1/2 OCLI	T-Band
2	3	1/4" Clear	3/16" Plate	Etched	2:6, 3:1	OCLI	Rimband
	4	1/4" Clear	3/16" Plate	Etched	2:6, 3:1	None	Rimband
	5	1/4" Clear	3/16" Plate	None	-	OCLI	Rimband
	6	1/8" Clear	0.05" Chemcor	1/2 Etch	~3:1	1/2 Metavac	Rimband
	7	1/8" Clear	0.05" Chemcor	None	-	Metavac	Rimband
	8	1/8" Clear	0.05" Chemcor	Etched	~3:1	Metavac	Rimband
	8A	1/8" Clear	0.05" Chemcor	Etched	~3:1	Metavac	Rimband
	8B	1/8" Clear	0.05" Chemcor	Etched	~3:1	Metavac	Rimband
3	11	1/8" Clear	0.05" Chemcor	Etched	~3:1	None	Rimband
	* 20	1/8" Clear	0.05" Chemcor	1/2 Etch	~3:1	1/2 OCLI	Rimband
	21	1/8" Clear	0.05" Chemcor	Etched	~3:1	None	Rimband
	22	1/8" Clear	0.05" Chemcor	Etched	~3:1	None	Rimband
	23	1/8" Clear	0.05" Chemcor	Etched	~3:1	None	Rimband
	24	1/8" Clear	0.05" Chemcor	Etched	~3:1	None	Rimband
	25	1/8" Clear	0.05" Chemcor	Etched	~3:1	None	Rimband
	26	1/8" Clear	0.05" Chemcor	Etched	~3:1	None	Rimband
	27	1/8" Clear	0.05" Chemcor	Etched	~3:1	None	Rimband
	** 29	1/8" Clear	0.05" Chemcor	Etched	~3:1	OCLI	Rimband
	** 30	1/8" Clear	0.05" Chemcor	Etched	~3:1	OCLI	Rimband

*Serial No. 20 was 1/2 etched and 1/2 OCLI coated because Serial No. 6, coated by Metavac, has a blue tint.
**Serial No.'s 29 and 30 were coated with OCLI HEA at the request of the FAA.

ATTACHMENT 1

ETCHED EXPERIMENTAL CRT PANEL PHOTOGRAPHS

Photos taken at FAA, NAFEC, on 4 November 1976 of an experimental 23" CRT bonded panel assembly consisting of an inner layer of 1/4" clear Lexan Polycarbonate and an outer layer of clear 3/16" glass. The glass outer surface includes six different areas as follows:



AREA	SURFACE TREATMENT
I	HEA Coating + 2.6 Etch
II	2:6 Etch Only
III	HEA Coating Only
IV	Clear Surface
V	HEA Coating + 2:2 Etch
VI	2:2 Etch Only

PHOTO NUMBER	DESCRIPTION
1	Reflections of ceiling mounted fluorescent lights in Areas II and III.
2	Reflection of ceiling mounted fluorescent light in Areas I and II.
3	Reflection of ceiling mounted fluorescent light in Areas I, II, III and IV.
4	Reflection of ceiling mounted fluorescent light in Areas III and IV.
5	Close-up of ATC data in Area I with reflection. Note resolution transition at bottom of photo between Areas I and III.
6	Close-up of ATC data in Area II with reflection. Note resolution transition at bottom of photo between Areas II and IV.
7	Close-up of ATC data in Area III with reflection. Note resolution transition at top of photo between Areas I and III.

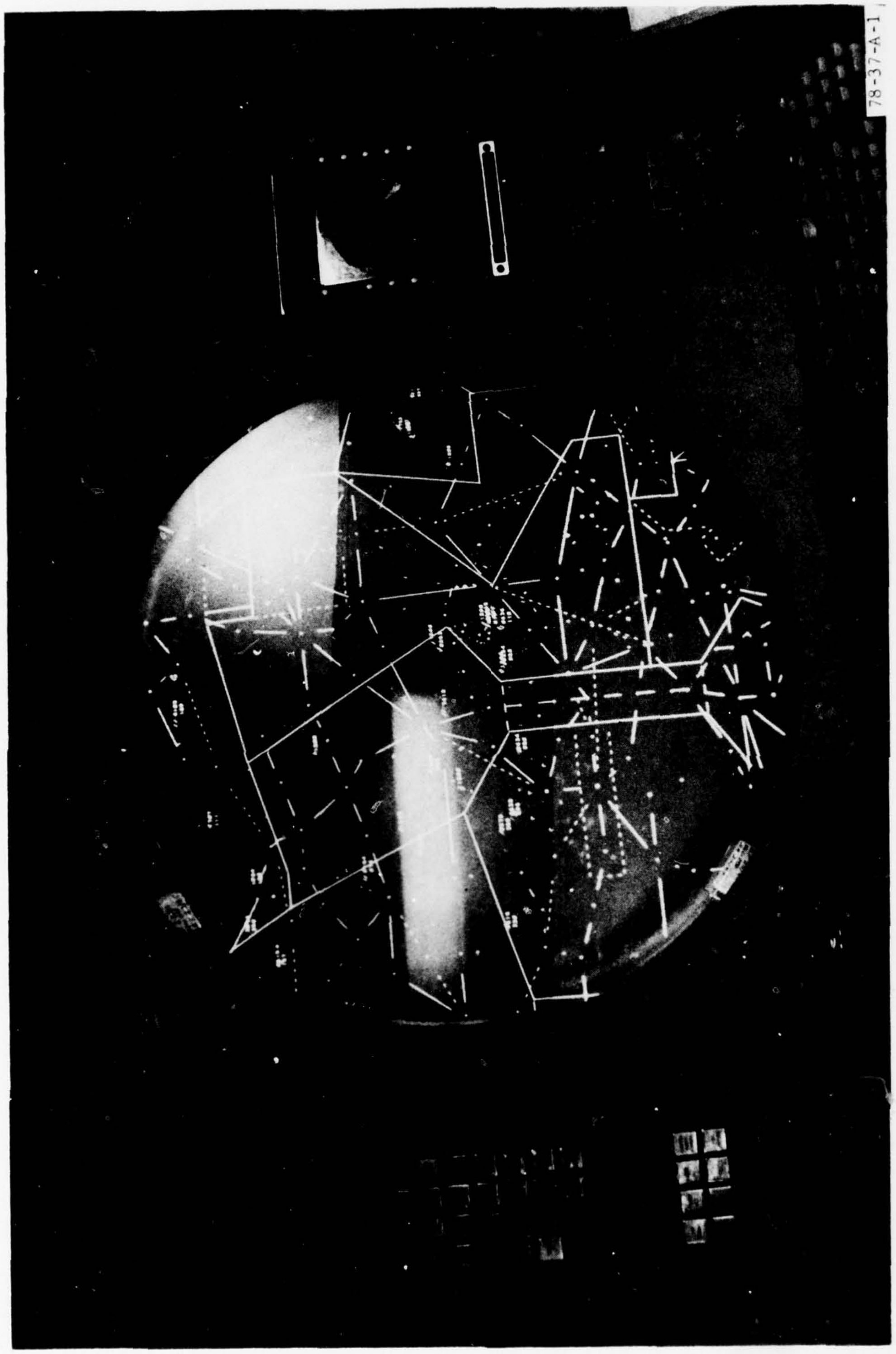


PHOTO NO. 1

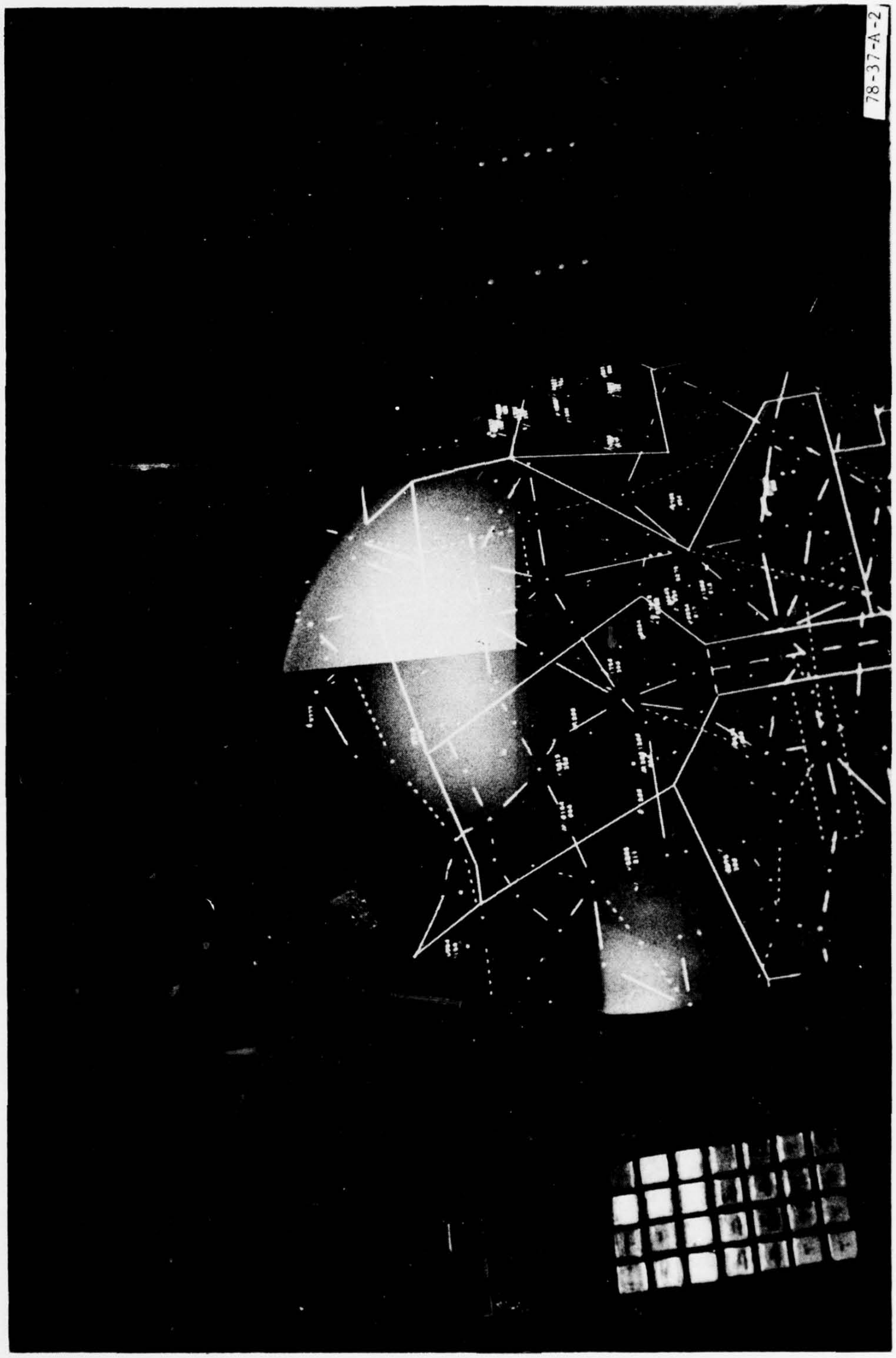


PHOTO NO. 2

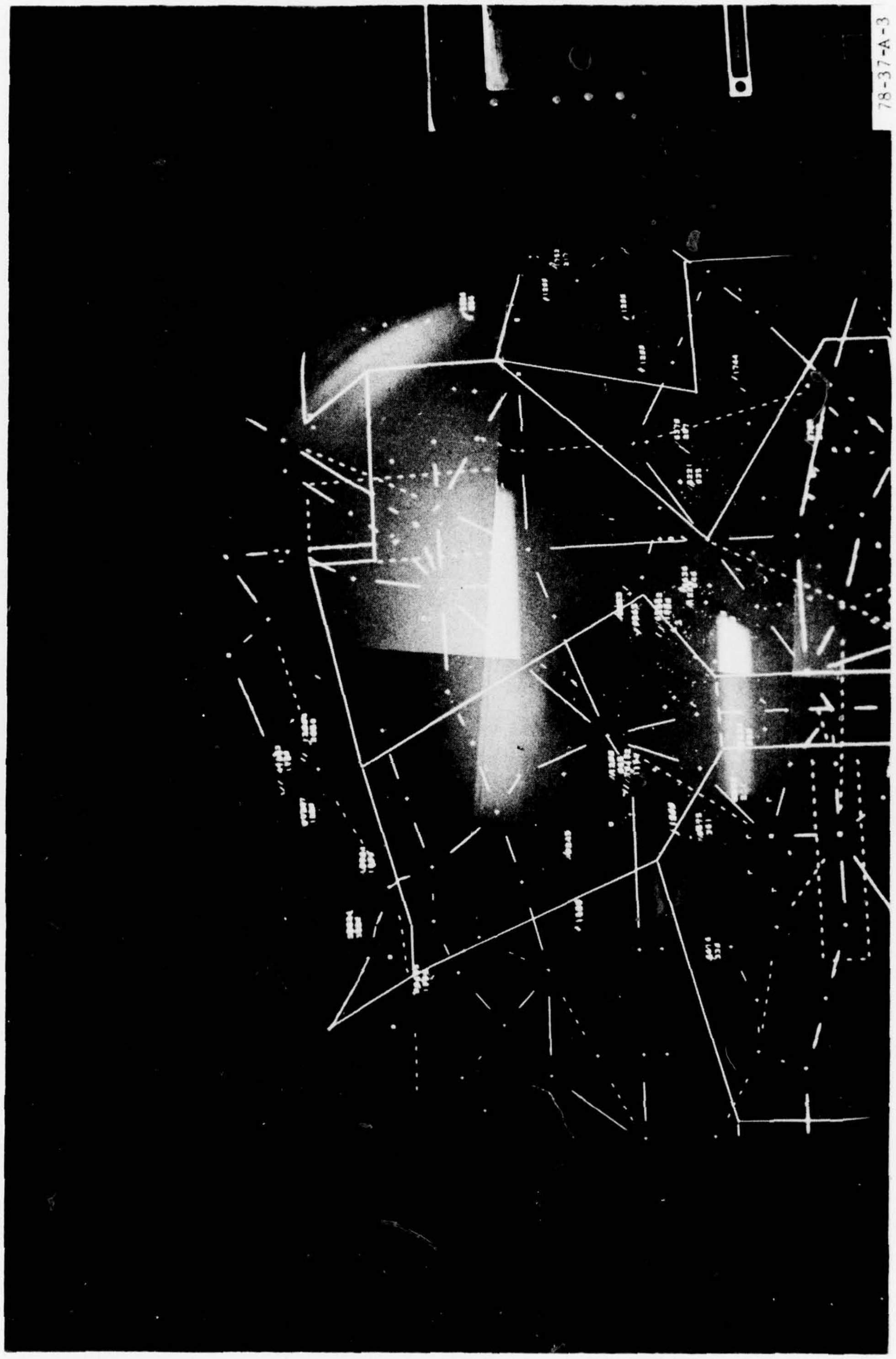


PHOTO NO. 3

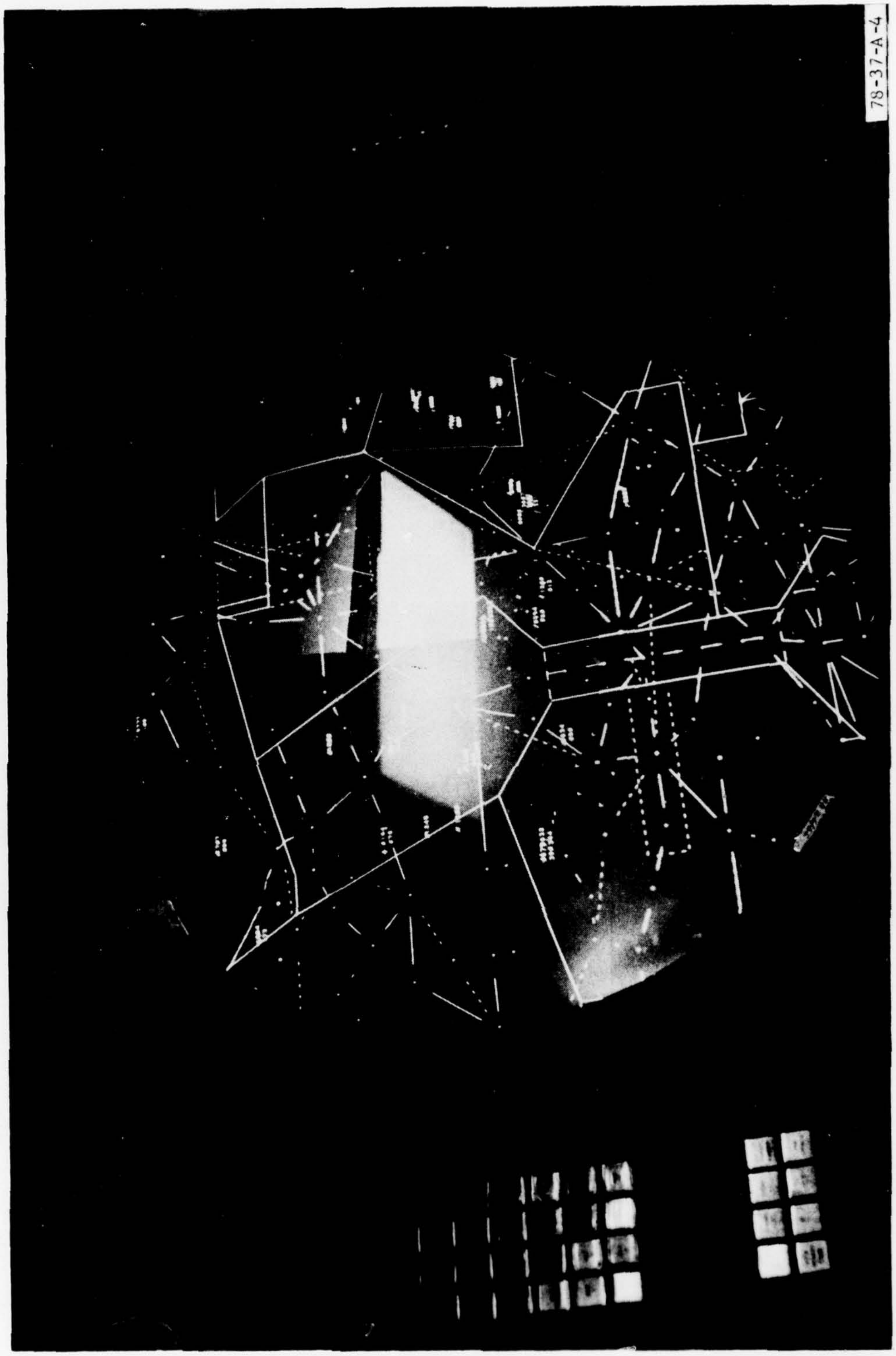


PHOTO NO. 4

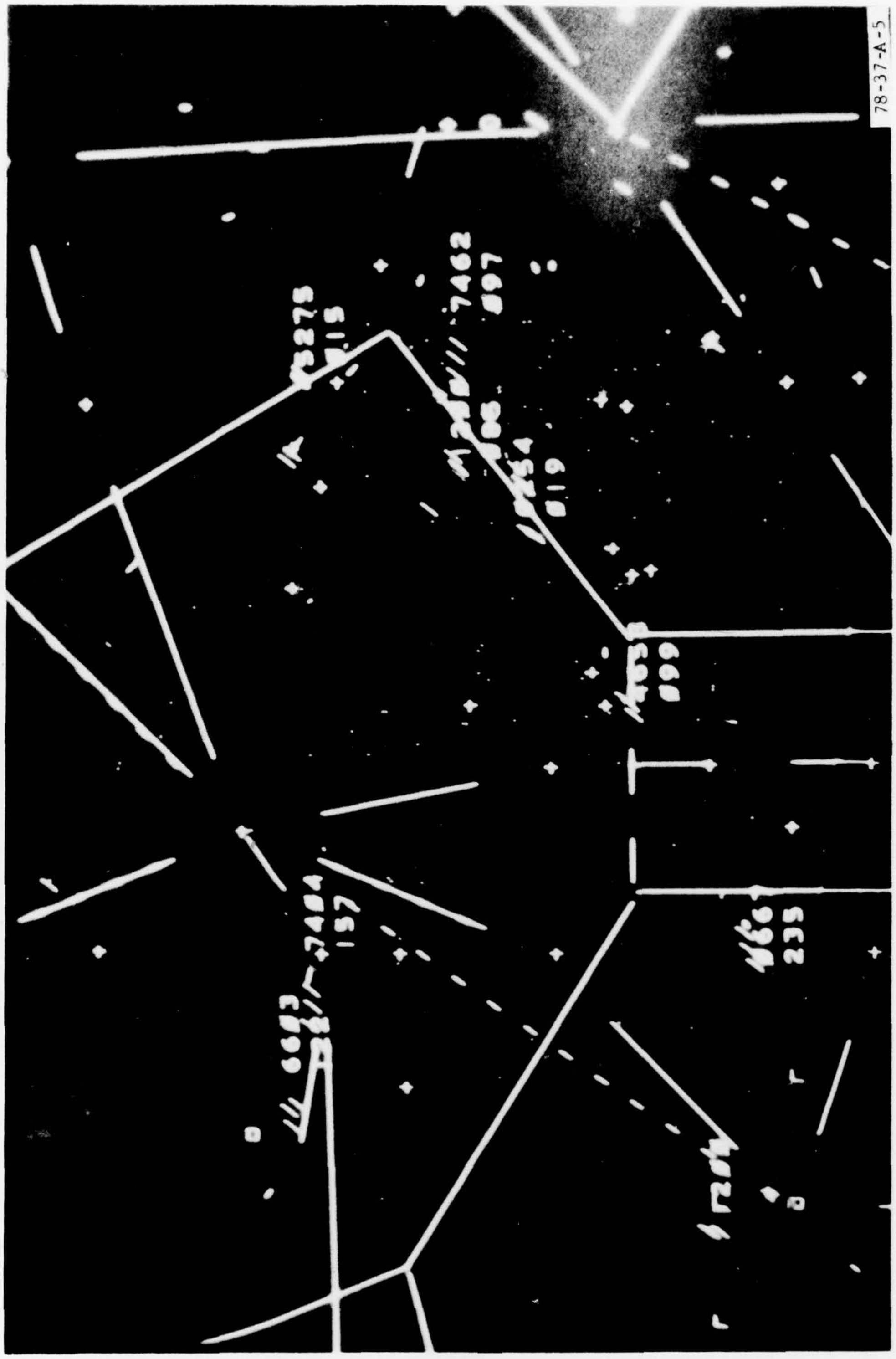


PHOTO NO. 5

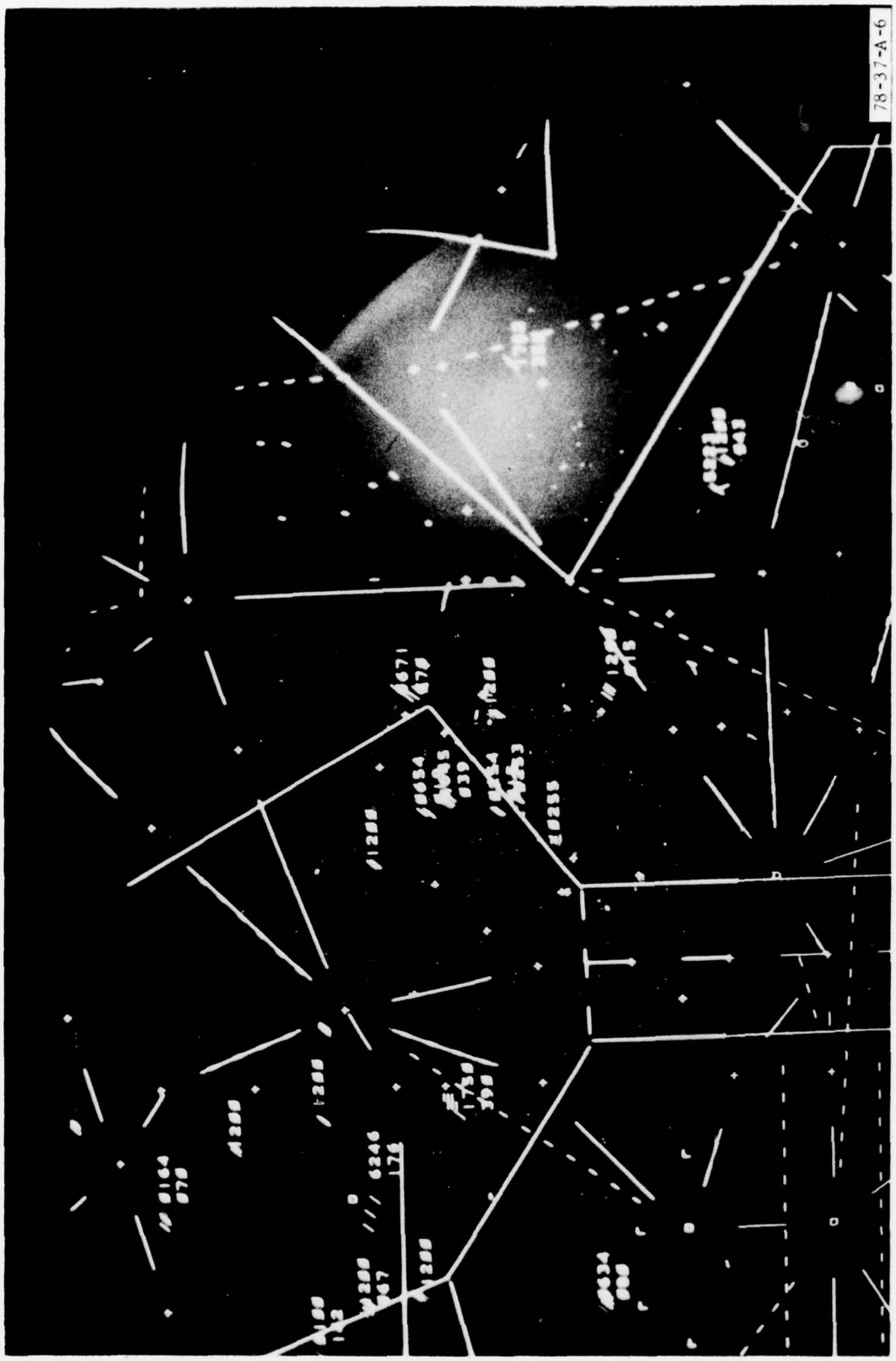


PHOTO NO. 6

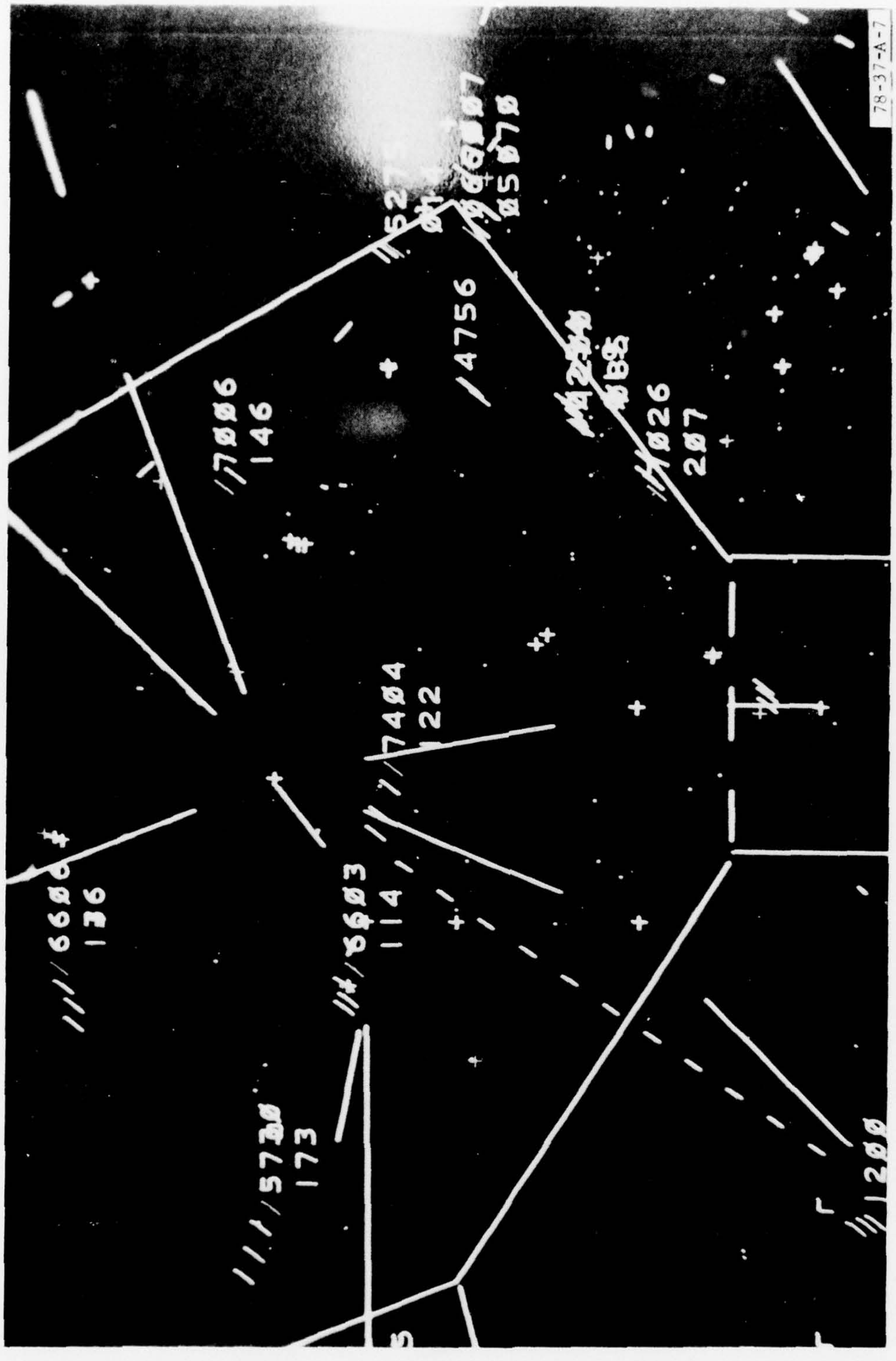
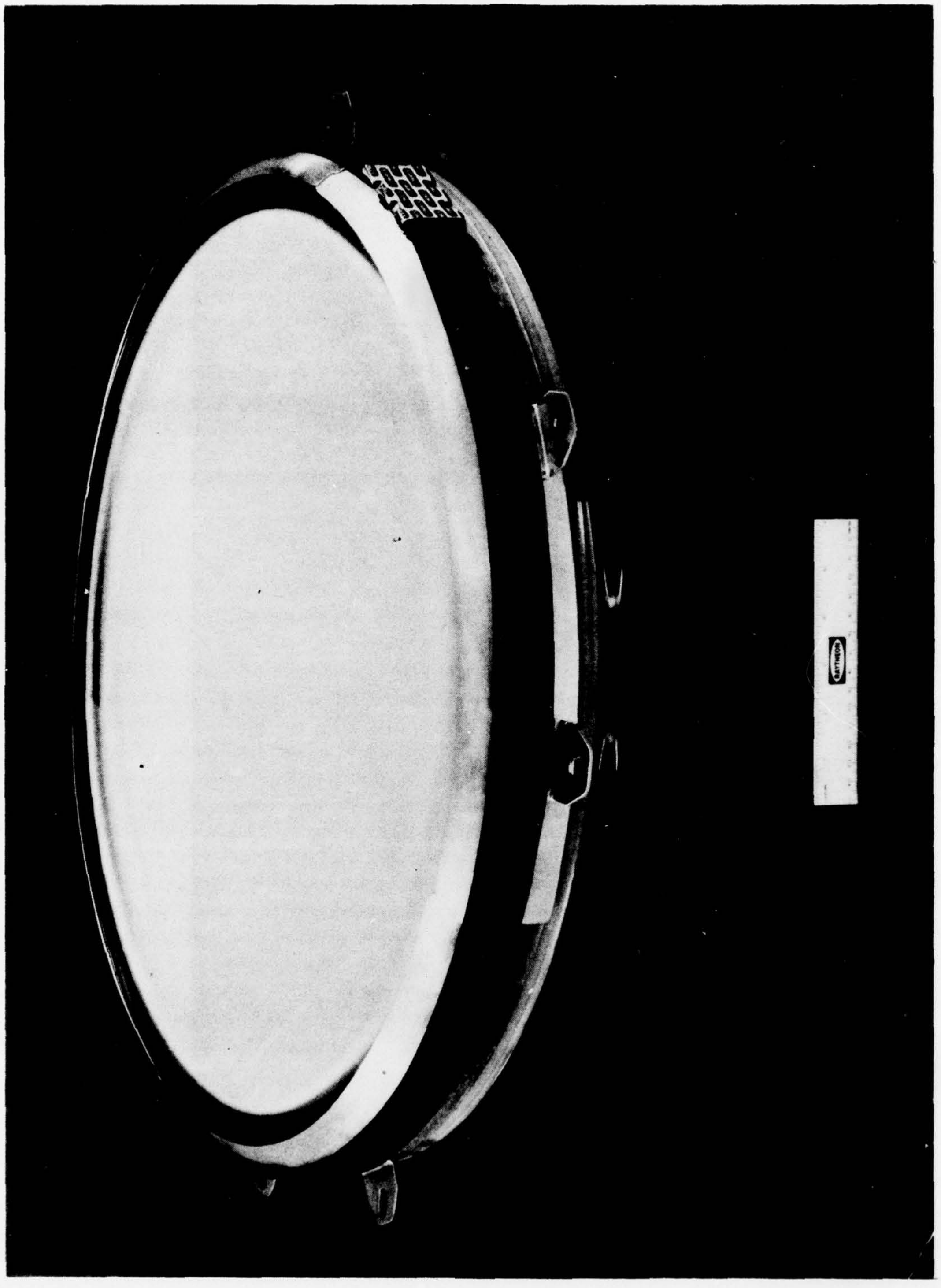


PHOTO NO. 7



23-INCH DIAMETER CRT WITH KIMCODE-TYPE RIMBAND

ENGINEERING AND MANUFACTURING PROBLEMS ENCOUNTERED AND SOLVED

Sandwich Thickness Reduction

The initial tubes had a composite sandwich implosion panel consisting of 0.250" lexan (T.M. General Electric Company),a bonding resin layer, and 0.188" outer glass panel. The sandwich was in turn bonded to the CRT face. The resultant extra resin layer and lexan added approximately .4" of additional distance from the phosphor to the outer surface. The material build up caused some diffusion of displayed data and increased the parallax between the phosphor and outer glass surface.

The composite sandwich thickness was reduced in the following two ways:

First: 0.125" lexan was substituted for the 0.250" lexan.

Secondly: The .188" outer glass panel was replaced by 0.050" Corning Chemcor (T.M. Corning Glass Works) Glass Implosion Panel.

Chemcor is a chemically strengthened glass manufactured by Corning Glass Works and is described in attachment 4 of this report. In addition to reduced thickness the outer chemcor panel has excellent abrasion resistance. It also is likely to break into small dice like pieces, rather than shatter, if sufficiently stressed during an implosion. Thus the new composite sandwich and resin is only 38% thicker than the original implosion panel and its resin.

Also, the transmission of these materials was such that the new CRT assembly could meet the same light output as the standard CK1498P31 CRT.

Etched Outer Panel

In order to increase viewability it was decided to etch the outer surface. The purpose of the etch was to render specular reflections from that surface incoherent. The initial problem was to determine the degree of etch to use. The etch was defined by viewing the USAF 1951 Resolution Chart through the panel. The first panels had etched in the 1:6 to 2:6 range. Some of these panels were bonded to CRT's. The following results were obtained:

It was found that as the etch became heavier -

1. Linewidth Increased.
2. Coherent Reflections Decreased.
3. Halos Around Dots and Lines Increased.

Conversely as the etch became finer -

1. Increase in Linewidth Became Less.
2. Coherent Reflections Increased.
3. Halos Around Dots and Lines Decreased in Intensity.

ENGINEERING AND MANUFACTURING PROBLEMS ENCOUNTERED AND SOLVED

The halos were due to scattering of the transmitted phosphor produced light by the etched surface.

Thus the best etch was the one that maximized the desired effects, i.e., reduced coherent reflections, while minimizing the unwanted properties. Several CRT samples were manufactured and tested by Raytheon. These were also evaluated by the FAA at NAFEC. The optimum etch was selected as 3:1 to 3:3 on the USAF 1951 resolution chart. The new CRT assembly was thus able to meet the linewidth (0.012") of the standard CK1498P31 CRT.

The outer glass panels that were used on the first CRT's were etched normally. However, it proved much harder to obtain a suitable etch on the chemcor panels. Raytheon worked closely with the vendor who etched the panels to obtain a uniform etch. The chemcor was subject to surface irregularities when etched.

Anti-Reflective Coating

It was felt that if the ambient light level of the ARTCC control room were raised the etch might not be sufficient to reduce unwanted reflections. It was decided to add an anti-reflective coating to the outer etched chemcor panel. Several vendors were used to provide AR coatings. Care must be taken when specifying coatings or selecting vendors as one coating exhibited an objectionable bluish hue.

Composite Sandwich Assembly Problems

Commercial and not optical quality lexan was only available for use. The lexan tended to have a variety of blemishes and scratches. Raytheon took precautions to only select the better lexan sheets for making composite sandwiches.

The extra layer of bonding resin was also a source of more defects (i.e., trapped air bubbles) as was the lexan. This is reflected by allowing more blemishes in the 454113-3 CRT specification (Sheet 18A).

There was also a minor problem of adequate adhesion of the lexan to the bonding resin at the circumference of the composite sandwich. This was overcome by using a primer on the lexan at its outer edge to improve bonding resin adhesion to the lexan.

Rimbands

The "T"-Band and eight separate mounting brackets were replaced by 4 identical rimbands with attached mounting brackets. The rimbands were epoxied to the CRT faceplate shoulder and a tension band was placed around the outside of the rimbands.

ENGINEERING AND MANUFACTURING PROBLEMS ENCOUNTERED AND SOLVED

Rimbands, Cont'd:

The new rim-band and brackets were designed such that the new CRT would fit directly into existing PVD's without any retrofitting. Details of the rimbands are shown in Figure 4A of Raytheon Specification Control Drawing 453113-3.

The rimbands and tension band place the CRT faceplate shoulder in compression. Thus if an implosion does occur the glass will tend to remain in place during airing of the tube.

Final Documentation

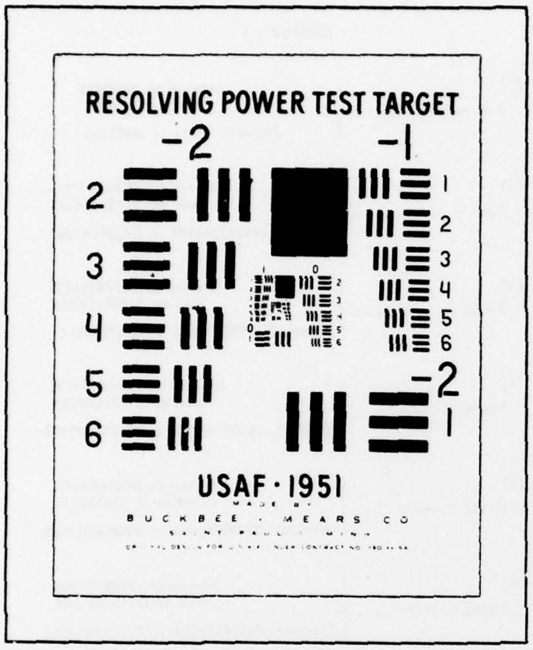
The final configuration has been designated as Raytheon tube type CK1798P31 and is described in the technical data sheet for that type. A complete description is given in Raytheon's Specification Control Drawing 453113-3.

APPENDIX B

USAF RESOLUTION CHART DATA

USAF RESOLUTION CHART DATA

NOMENCLATURE AND SPECIFICATIONS



The proportionality of the line and element dimensions is given by the ratio of the unit widths of two subsequent elements. This ratio shall be the sixth root of two. At the head of every group shall be a group number indicating the number of li/mm of the largest pattern within the group in terms of powers of two. For example, a group number K-3 shall indicate eight li/mm for the largest pattern of this group. The group numbers shall be whole numbers, for example—1, 0, 1 etc. Within a group, every element shall be designated by an element number n = 1 (number 1 belonging to the largest element) through number 6 (number 6 belonging to the smallest element). The resolving power R represented by the element n of group K of the target can then be calculated from the equation.

$$R = 2^{K \text{ plus } \frac{n-1}{6}}$$

Thus element 1 of group —2 has 0.25 li/mm, element 1 of group —1 has 0.5 li/mm, and element 1 of group 0 has 1 li/mm.

The range of the target shall include ten target groups from 0.25 to 227.5 li/mm or from group —2 to group 7.

Interval—a line or a space.
Unit—a line and the adjacent space.
Pattern—three lines and two included spaces.
Element—an arrangement of two patterns set at right angles to each other and separated by one unit width.

GROUP —2

		Interval	Unit	Element
(1)	.25 li. m/m	.07874	.15748	.94488 × .3937
(2)	.280625 li. m/m	.07014699	.14029398	.84176388 × .35073495
(3)	.317475 li. m/m	.06200488225	.1240097645	.744058587 × .31002441125
(4)	.356175 li. m/m	.0552677756	.1105355513	.6632133078 × .27633887825
(5)	.3994 li. m/m	.0492864296	.0985728592	.5914371552 × .246432148
(6)	.44545 li. m/m	.04419126725	.0883825345	.5302952124 × .2209563385

GROUP —1

		Interval	Unit	Element
(1)	.50 li. m/m	.03937	.07874	47244 × .19685
(2)	.56125 li. m/m	.03507349665	.0701469933	.4208819598 × .17536748325
(3)	.63495 li. m/m	.0310024411	.0620048822	.3720292932 × .1550122055
(4)	.71235 li. m/m	.0276338878	.0552677756	.3316066536 × .138169439
(5)	.7988 li. m/m	.0246432148	.0492864296	.2957185776 × .123216074
(6)	.8909 li. m/m	.0220956336	.0441912672	.2651476032 × .110478168

GROUP + 0

(1) 1 li. m/m — Interval = .019685
Unit = .03937
Element .23622 × .098425

(2) 1.1225 li. m/m — Interval = .01753674832
Unit = .03507349665
Element .2104409799 × .087683741625

(3) 1.2599 li. m/m — Interval = .01550122056
Unit = .03100244113
Element .18601464678 × .077506102825

(4) 1.4142 li. m/m — Interval = .01381694391
Unit = .02763388783
Element .16580332698 × .069084719575

(5) 1.5874 li. m/m — Interval = .01232160741
Unit = .02464321482
Element .14785928892 × .06160803705

(6) 1.7818 li. m/m — Interval = .01104781681
Unit = .02209563362
Element .13257380172 × .05523908405

GROUP + 1

(1) 2 li. m/m — Interval = .0098425
Unit = .019685
Element 11811 × .0492125

(2) 2.245 li. m/m — Interval = .00876837416
Unit = .01753674832
Element .10522048992 × .0438418708

(3) 2.5398 li. m/m — Interval = .00775061028
Unit = .01550122056
Element .0900732336 × .0387530514

(4) 2.8494 li. m/m — Interval = .00690847195
Unit = .01381694391
Element .08290166346 × .034542359775

(5) 3.1952 li. m/m — Interval = .0061608037
Unit = .01232160741
Element .07392964446 × .030804018525

(6) 3.5636 li. m/m — Interval = .0055239084
Unit = .01104781681
Element .06628690086 × .027619542025

GROUP + 2

(1) 4 li. m/m — Interval = .00492125
Unit = .0098425
Element .059055 × .02460625

(2) 4.49 li. m/m — Interval = .00438418708
Unit = .00876837416
Element .05261024496 × .0219209354

(3) 5.0796 li. m/m — Interval = .00387530514
Unit = .00775061028
Element .04650366168 × .0193765257

(4) 5.6988 li. m/m — Interval = .003454235975
Unit = .00690847195
Element .0414508257 × .017271177375

(5) 6.3904 li. m/m — Interval = .00308040185
Unit = .0061608037
Element .0369648222 × .01540200925

(6) 7.1272 li. m/m — Interval = .0027619542
Unit = .0055239084
Element .0331434504 × .013809771

GROUP + 3

(1) 8 li. m/m — Interval = .002460625
Unit = .00492125
Element .0295275 × .012303125

(2) 8.98 li. m/m — Interval = .002192093541
Unit = .00438418708
Element .02630512248 × .0109604677

(3) 10.1592 li. m/m — Interval = .001937652571
Unit = .003875305142
Element .023251830852 × .009688262855

(4) 11.3976 li. m/m — Interval = .001727117989
Unit = .003454235979
Element .020725415874 × .008635589475

(5) 12.7808 li. m/m — Interval = .001540200926
Unit = .003080401852
Element .018482411112 × .00770100463

(6) 14.2544 li. m/m — Interval = .001380977101
Unit = .002761954203
Element .016571725218 × .0069048855075

(2 of 3)

GROUP + 4

(1)
16 li. m/m
Interval = .0012303125
Unit = .002460625
Element .01476375 × .0061515625

(2)
17.96 li. m/m
Interval = .00109604677
Unit = .002192093541
Element .013152561246 × .0054802338525

(3)
20.3184 li. m/m
Interval = .000968826285
Unit = .001937652571
Element .011625915426 × .0048441314275

(4)
22.7952 li. m/m
Interval = .000863558994
Unit = .001727117989
Element .010362707934 × .0043177949725

(5)
25.5616 li. m/m
Interval = .000770100463
Unit = .001540200926
Element .009241205556 × .003850502315

(6)
28.5088 li. m/m
Interval = .000690488550
Unit = .001380977101
Element .008285820606 × .0034524252525

GROUP + 5

(1)
32 li. m/m
Interval = .00061515625
Unit = .0012303125
Element .007381875 × .00307578125

(2)
35.92 li. m/m
Interval = .000548023385
Unit = .00109604677
Element .00657628062 × .002740116925

(3)
40.6368 li. m/m
Interval = .0004844131425
Unit = .000968826285
Element .00581295771 × .0024220657125

(4)
45.5904 li. m/m
Interval = .000431779497
Unit = .000863558994
Element .0051813053964 × .0021588772485

(5)
51.1232 li. m/m
Interval = .0003850502315
Unit = .000770100463
Element .004620602778 × .0019252511575

(6)
57.0176 li. m/m
Interval = .000345244275
Unit = .00069048855
Element .0041429313 × .001726221375

GROUP + 6

(1)
64 li. m/m
Interval = .000307578125
Unit = .00061515625
Element .0036909375 × .001537890625

(2)
71.84 li. m/m
Interval = .0002740116925
Unit = .000548023385
Element .00328814031 × .0013700584625

(3)
81.2736 li. m/m
Interval = .000242206571
Unit = .000484413142
Element .002906478852 × .001211032855

(4)
91.1808 li. m/m
Interval = .0002158897485
Unit = .000431779497
Element .002590676982 × .0010794487425

(5)
102.2464 li. m/m
Interval = .0001925251157
Unit = .0003850502315
Element .002310301389 × .00096262557875

(6)
114.0352 li. m/m
Interval = .0001726221377
Unit = .0003452442754
Element .0020714656524 × .0008631106885

GROUP + 7

(1)
128 li. m/m
Interval = .0001537890625
Unit = .000307578125
Element .00184546875 × .0007689453125

(2)
143.68 li. m/m
Interval = .0001370058463
Unit = .0002740116926
Element .0016440701556 × .0006850292315

(3)
162.5472 li. m/m
Interval = .0001211032856
Unit = .0002422065713
Element .0014532394278 × .00060551642825

(4)
182.3616 li. m/m
Interval = .0001079448743
Unit = .0002158897487
Element .0012953384922 × .00053972437175

(5)
204.4928 li. m/m
Interval = .0000962625578
Unit = .0001925251157
Element .0011551506942 × .00048131278925

(6)
228.0704 li. m/m
Interval = .0000863110688
Unit = .0001726221377
Element .0010357328262 × .00043155534425

300 li./m m

(20)

Interval = .000065616666
Unit = .00013123333
.00078739998 × .000328083325
.0157479996 × .0065616666

34170

(3 of 3)

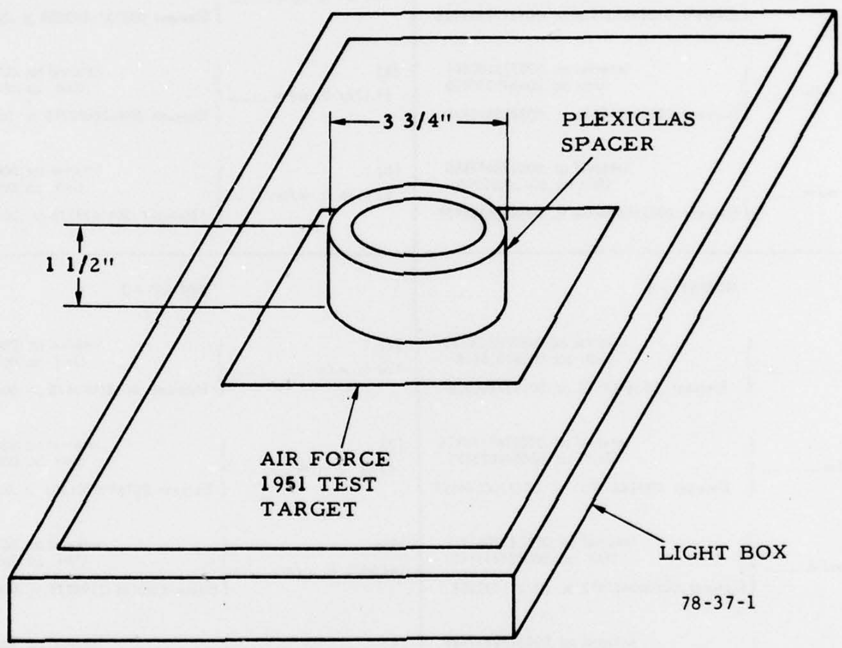


FIGURE B-1. RESOLUTION TEST JIG FOR CHECKING CRT SURFACE ETCHING

APPENDIX C

EFFECTIVENESS OF ANTIREFLECTIVE TREATMENTS TO PVD'S

Instructions

Based on earlier tests, the various antireflective treatments have been reduced to two basic alternatives. These are the two that seem to be most cost effective, an etch process and a coating. Both are illustated alone and in combination on the four-sector display, the fourth sector being an illustration of the effect of removing the glass cover from a PVD. Please examine reflections, glare, and the utility of the situation display for control purposes as you see them on the normal, unmodified PVD (labeled C for control), and on the treated PVD (labeled T for antireflective treatment). Mark the questions below to indicate the results of this C versus T comparison.

After making the C versus T comparison, please examine the four-sector PVD. Compare first the treated upper left quadrant with the untreated lower-right quadrant. This comparison will allow you to rate the relative importance of the PVD treatment versus the reduction in reflections caused by removing the glass cover. Second, please compare the remaining two quadrants; the upper-right section has a coating and the lower-left section has an etch treatment. While both of these methods reduce reflections to a degree, there is a cost difference that makes it desirable to rate them against each other.

1. Comparing the treated PVD (console T) with the normal PVD (console C) is the reduction in glare and reflections that you see on the treated PVD sufficient to meet the requirement of the controller?

YES 8 NO 0

2. Comparing the treated PVD with the normal PVD is the resolution and detail in the situation display preserved to a satisfactory degree in the console labeled T?

YES 8 NO 0

3. Is the treated console situation display satisfactory for control use?

YES 8 NO 0

4. On the four-sector PVD, is the treated upper-left sector significantly better than the lower-right sector with no glass cover but no special treatment?

YES 8 NO 0

5. Of the remaining two sectors, which is best for control use?

PREFER THE COATED UPPER-RIGHT 5

PREFER THE ETCHED LOWER-LEFT 3